

Is Brain in a Superfluid State? Physics of Consciousness.

Benoy Chakraverty **

Contents

1	Introduction	2
2	Quantum Information Field	5
2.1	Self Operators and Coherent Brain State	11
2.2	Synaptic Self and Spontaneous Symmetry Breaking	16
2.3	Thermodynamics of Cognitive Order	21
3	Cognitive Response	25
3.1	Cognitive Response and Consciousness	25
3.2	Memory and dynamics of Perception	29
4	Discussion	35
5	Appendix	38
6	Conclusion	41

Abstract

We set up the human brain as a quantum field of Information in the cognitive functional space of the mind. To this end, a quantum operator s is introduced which will create information like particle (called *infons*) and generate a coherent macroscopic information field. *This operator represents self and reflects our genetic identity.* The non-zero average of this non-hermitian operator, denoted by $\langle s \rangle$ is defined as the cognitive self usually referred to as the first person \mathcal{I} in our everyday life. A local field operator ψ_i is defined that generates infons at neuronal synaptic sites i . We impose the identity of synaptic self $\langle \psi \rangle$ with the cognitive self \mathcal{I} . We establish consciousness as the causal cognitive response function of brain or a susceptibility to the external world. We show that at the emergence of $\langle s \rangle$, self-consciousness rises out of consciousness. This is reflected precisely by divergence of the susceptibility function; an infinitesimal perturbation due to external world becomes an incredibly intense cognitive experience. We point out that a child at birth has cognitive response but without having developed the $\langle s \rangle$ average or \mathcal{I} —consciousness until later. A state of unconsciousness or of sleep is a ground state, precisely the state

where cognitive response to the exterior world is zero but the self or \mathcal{I} remains perfectly well defined and in repose. The *non-zero* $\langle s \rangle$ average is the result of perfect phase coherence of the coherent information field in the brain with a fixed phase angle θ which represents a symmetry breaking transition (establishment of subjectivity with respect to an objective world). Excitation from this phase coherent ground state of the information field is shown to constitute our consciousness. We also point out the underlying structure of the dynamic memory matrix in terms of time correlation of these self-operators.

****B.K.Chakraverty** is a former director of Laboratoire de Transition de Phase, C.N.R.S and has been a research staff member of the Solid State Theory Group of C.N.R.S, Grenoble. He has been Emeritus director of research, at Centre National de Recherche Scientifique, Grenoble, France.
e-mail: benoy_chakraborty@hotmail.fr

1 Introduction

Physics have come a long way since the days of Newton and Galileo when it was mainly devoted to investigations of celestial bodies. Today there is virtually no frontier that is forbidden to the methodology of physical investigation; from stock-market to big bang passing thorough meteorology and subatomic particles, physics tries to bring an unifying framework to the investigating mind. The mystic of brain since time immemorial, the difficulty of doing experiment in vivo, the belief that mind and brain have nothing to do with each other had prevented progress in the field until very recently. There had been in the past several classes of approach to the brain-phenomena. There has been work revolving around the theory of neural networks and dynamical systems [1] [2] [3]. These approaches have the congenital difficulty of never giving emergence of the higher brain functions or consciousness like phenomenon. Then there had been conjectures that brain is quantum. This goes as far back as Bohr, and as recently as R.Penrose [4] [5] [6]. There also has been suggested mechanisms for these quantum aspects [7] [8] [9]. The approach in this paper is distinctly different. For the very first time one is introducing the concept of *Self* as a quantum operator reflecting genetic identity and through the operation of this operator we have created a quantum information field. Certain parts of this paper has echoes of Quantum decision theories [10]

In the last twenty years or so there has been an explosion of sophisticated experimental techniques like Magnetic Resonance Imaging (MRI), Functional Magnetic Resonance Imaging (fMRI), Positron Emission Spectroscopy (PET), Near-Infrared Spectroscopy (NIRS), Electroencephalography (EEG), Magnetoencephalography (MEG) along with Computerised Tomography & variety of Multi-modal Imaging to track diseases of the brain but also study neural anatomy as well as its response to a variety of stimuli. One can now study some of the brain activity in-situ as well as in real time (fMRI can produce four images every second. The brain takes half a second to be conscious of stimuli). Since the pioneering activity of the noted brain surgeon Wilder

Penfield[11] who introduced electrodes into the brain to chart out the somato-sensory map of the cortex and elicited memory pattern by proper excitation of neural region, neurologists today are capable of pinpointing their electrode on one single neuron and observe what happens.

Today we know a great deal about neurons, the primary agent that carry signals to and fro between world outside and our brain inside. The human brain is estimated to have about a hundred billion nerve cells or neurons, two million miles of axons that take the signal down to its near neighbors and a million billion synapses, the switch that connects one neuron with another [12]. Knowledge about the physiology and the architecture of dendrites, neurons and their axons with its synapse has developed enormously over a century [13]. We now know that behind every single set of information, feeling, sensation, thought or action, a set of neurons are involved and that there is no reason to live in the twilight of Cartesian duality [14] of relegating brain in some physical space and mind elsewhere in some mental space. It would be simpler to assume that both space is contained in the same Hilbert space where reality is played out whether it is all measurable or not and that all of which goes on in the brain is negotiated by the incessant flickering of these myriads of neurons, some of them firing in unison, in a pattern with perfect inner coherence. Their populations as well as their connections are evolutive, never static, always adapting, developing according to ebb and flow of information from the outside world as well as to the needs of the living self. Everything that we do, whether experiencing an event or an emotion as we listen to Ravi Shankar or Beethoven, our thought whether sublime or murderous, our imagination, our desire, our acting out our will, every single thing that becomes fabric of our mind is so because of this neural network that subtends the mental space, that Sherrington had named the ‘enchanted loom’[15]. We assume that there is no little ‘man’ or a homunculus sitting in a corner of the brain, pulling the strings of some Cartesian theater. The Hilbert space [16] where quantum mechanics acts out, is also the mental space of brain. In this space new quantum operators will be defined and asked to operate in perfect accordance with the laws of causality and of thermodynamics.

On 15th january 2008, a monkey standing on a treadmill in a U.S Neurology laboratory with electrodes planted in some of her motor neurons made history by making a robot stationed in Tokyo move its legs by the simple transfer of the energy of her thoughts [17]. The day is not far when paralytics will be able to control artificial hands and legs through their thoughts alone. Our central assumption is based on the simple belief that thoughts and emotions carry energy and as such physics of consciousness can be constructed from first principles.

We consider that actions of the mind can be formulated through quantum mechanical formulation, with operators operating on Hilbert space which is an extension of what we call our physical Hilbert space. We shall show why the quantum description is appropriate here: continuous deformation of neural medium is postulated to lead to discrete energy packets that we identify as information in the mind. The quantum operators that we shall introduce are

operators of self. We designate them by S since they create states or information like particles for cognitive functions $\{\alpha\}$. It is these states we shall define as forming the armature of the *mental space*. We will show that these states are formed by fundamental excitations or discrete information quanta that we call infons. Infons are considered to be excitation out of mind field. These excitations are taken to be boson like because a great number of them can be imagined to be packed into a given function. These are taken to be indistinguishable particles. This fundamental indistinguishability separates quantum mechanics from classical mechanics; the classical particles move in distinguishable space-time orbits which can be tracked continuously while this is not true of quantum objects. From mental space we go to neural space and assume that neurons vehicle these excitations, that they can be exchanged from one neuron to another. Only when these boson-like information packets develop a coherent macroscopic character by organising themselves into distinct states or functions $\{\alpha\}$, that we become aware of them as distinguishable entities, as joy or pain or as good or bad. We can use the analogy with electrons; they are indistinguishable particles. But the way they organise, as they go from hydrogen atom to Uranium, forming distinguishable orbits that each atom becomes different from its constituting electrons and eventually completely different, from each other giving us the infinitely rich periodic table of elements.

Our objective is to generate a global macroscopic coherent state of information for the brain by repeated application of these S operators using a neuron or assembly of neurons to organise these function states. We show that a macroscopic global coherent state of the cognitive space will emerge. This coherent state is the eigenfunction of the global S operator and whose eigenvalue is brain's cognitive order parameter. The resultant phase coherence is key to the whole smooth cortical synchrony or symphony.

In the next section we develop the phenomenology of the coherent brain state. In section 2, we present the coherent state for a single cognitive function α and go on to form a global coherent state out of a bouquet of functions. To do so, we use the coherent state formalism, due to Glauber, so called Glauber state[18].

We replace the 'real brain' by an organised neuron network of neurons in the cortex communicating with each other through their synaptic connections. We take a model brain, containing a lattice of *synaptic sites in the cortex* connected with each other through axon terminals that gather its input through a mesh of dendrites. This is a far cry from the highly complex human brain that has evolved over several hundred thousand years since the Homo sapiens. We show how such an assembly has phase coherence naturally built in and that stays in man all his life. It is at this stage that the global S operator develops a macroscopic value and a non-zero average value $\langle S \rangle$. *The central idea of this paper, consists in identifying this operator average as our quintessential self.* An internal executor emerges in our mind, the " \mathcal{T} " that most people say they feel exists inside their head!

In the subsection 2.2 we will write down the thermodynamic arguments of the emergence of this $\langle S \rangle$ average and associated spontaneous symmetry breaking.

In the section 3, *we introduce the novel idea that what we call consciousness is nothing but a cognitive response of the neural brain to the world.* This response function or cognitive susceptibility will be defined in terms of these operators and applied to different states of the brain. Section 4 will discuss some of these results.

We may summarise this introduction by reiterating that our objective is not whether physics can solve some of the problems of human brain (it probably can't, like anybody else !) but whether it will allow us to think reasonably about some of these problems.

The noted eighteenth century French physician Pierre Cabannis once said that 'Brain secretes thought as liver secretes bile' [19]. This is almost true. Actually the function of the brain is to create representation of the world out of the flood of incoming electro-chemical signals that neurons vehicle; these signals are basically all alike yet their representations in our mind are indescribable in their infinite richness and variety.

2 Quantum Information Field

Mental space is taken to be a quantum information field and we suggest that a normal functioning brain is a coherent state of this field. Why quantum and not classical?

We ought to precise what kind of a quantum particle are we considering an information to be— electron like or photon like ? This is a legitimate question since the classical and quantum limits of these two elementary particles are slightly different. Electromagnetic theory of Maxwell derived its analogy from classical fluid motion. Classical electromagnetic theory works because in a classical light beam millions of photons are involved where photon occupation is a continuous variable. One did not worry about discrete nature of this number, neither did one know that a single photon existed. Hence in this limit quantum theory or corpuscular description was not needed and wave description was adequate. As far as electron went, in the beginning, it was just the very opposite. The electron was just a particle and like any other particle had a mass living at some point in space and time with a definite velocity or momentum and obeyed Newton's laws of motion. It was perfectly classical. Its quantum wave nature was discovered much later with Schrodinger and de Broglie and then came with it, the Heisenberg uncertainties of not knowing simultaneously its position and momentum. It is one of the paradox of quantum mechanics that one can hardly describe a single photon or able to write a wave function for a single photon. Neither can one localise a photon. It was shown very early [20] that this difficulty came from the fact that there was no position operator for a photon. As a result, a single photon's probability density or probability amplitude, its wave function at a space point can neither be written down or normalised to unity over the space. A quantum particle on the contrary can be described perfectly by the Schrodinger wave function $\psi(x)$ and like an electron can be localised. Its probability density given by $\int |\psi(x)|^2 dx$, where $\psi(x)$ is

the probability amplitude to find the particle at a space point x , is perfectly normalisable and is a conserved quantity.

The choice we have made is to take information as a discrete particle like object rather than like a photon. We consider that in a normal human brain only an infinitesimally small amount of neural space is occupied by these particles and as a result classical wave description like that of a light beam is inappropriate. On the other hand why do we think that these particles are quantum like than classical? One of the principal characteristic of a classical particle that it can be prepared precisely at a space point x_o with a precise momentum p_o ($p_o = mv$). The limits of precision can be as fine as we want and is $\Delta x_o \Delta p_o = 0$. This is basically because x & p are independent quantities for a classical particle and we can vary one without varying the other. We can measure one without disturbing the other and we can measure both at the same time. All this is not true of a quantum particle. The two quantities x and p are not independent for a quantum object, they are conjugate. They do not commute which means that these two quantities cannot be measured simultaneously and if one measures x one disturbs p and vice versa. This brings an uncertainty in the measurement given by the famous Heisenberg's relationship

$$\Delta x_o \Delta p_o = \hbar$$

Here \hbar is the Planck's constant. For a classical particle if we prepared it at the point x_o it would remain there eternally unless acted upon by external force which is Newton's equation of motion. For a quantum particle on the other hand, if we did the same thing and we insist on the particle being immobile at x_o it will not do so. There will be one or two things: either we will find the particle at x_o but we will find it at wild values of p_o or we will find it with a momentum p_o but its location will be anywhere in the space, with a probability given by the Schrodinger wave function $\psi(x)$. A classical baby in the cradle will remain in the cradle while a quantum baby will not remain localised but will ooze away, much to the consternation of the mother (but since $\int |\psi(x)|^2 dx = 1$), mother is bound to find her baby) !

There is a fundamental reason for this quantum behaviour. In classical physics particle motion is deterministic, determined by laws of Newton, governing a particle's position and its velocity. These laws are explained by Hamilton's principle which says that trajectory a particle will choose is determined by the principle of least action; of all the possible paths a particle may take, the most probable one is the one that costs least action.

This least action path is the only path that a classical particle will take (path 0 of $A - A'$ figure 1). If we consider the action path as a possible program, a classical information particle will execute the same program again and again. By its very nature our mind and consequently our brain is supposed to have free will. This means that there is no guarantee an information particle will take the least action path in order to execute a given function. It may well choose a variety of paths of which the least action path is just one. Many of its paths will go over higher energy hills and sum total of these excursions constitute

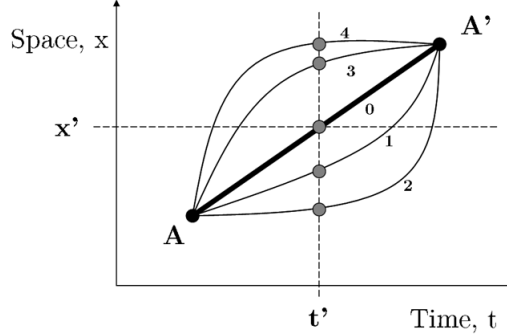


Figure 1: Classical and Quantum Paths of an Information Particle in the Neuron

the Feynman path integrals [21]. At any instant of time t' , (See Figure 1) the information particle may well stray away from its classical path 0 (point x', t') and be found on points indicated on the trajectories 1, 2, 3, 4, although its field amplitude $\psi(x, t)$ must obey $\int_x |\psi(x, t')|^2 dx = 1$. Getting away from the classical path, gives these information particles an infinite degrees of mental freedom, which is the reason why we can suddenly change our mind in course of an action and take a completely different path. A computer as it is today does not have free will and is condemned to obey the programs that had been prewritten. A computer is classical even if it borrows neo-classical algorithms for its functioning. It is in this strict sense information particles are quantum objects. *What their paths minimise is certainly not action but perhaps risks involved in the action and mind will choose the path of minimum risk.*

An information particle is created at some synaptic site i but it does not remain localised there; it hops from synapse to synapse and eventually joins other information bits to create a coherent message. It is hopeless to ask where a specific bit of information resides; it is delocalised, it is disincarnate, it is everywhere and nowhere. Coherent cognitive functions they perform can be localised and are identifiable in space and time but, not the information bits themselves.

This is why mental space is a quantum information field. These quantum particles can only be generated by application of some operator on some occupation number vectors that describe the Hilbert space of the mind. Only a quantum description will be able to capture the underlying physics.

To start with, we have the electro-chemical signals that are coming through different sensory channels, which seem perfectly banal, varying only in its intensity (frequency) and duration and yet each one will become a discrete excitation or a bit of information, exactly where and how nobody knows. Probably the transformation (transmutation or transcription) occurs at the somatic center of each neuron from where it will go out towards other neurons through its axon as

an action potential eventually to its synapse. The scenario of "information" generation in the brain may be following. Neural medium in the brain reacts to the changing electro-chemical potential of its surrounding neurons whenever it is disturbed by the outside world. This disturbance generates a wave like oscillation pattern in the medium that the mind perceives as a sensation or "information" coming in. *A plane monochromatic distortion wave can carry no information*; this is equally true of a monochromatic light beam that cannot transport any signal, unless it is frequency or amplitude modulated. If the "meaning" vector of a distortion wave is taken as amplitude of some perfectly sinusoidal wave pattern, then evidently, summed over a few oscillation, the meaning adds to zero for a monochromatic wave of wavelength λ . Basically an organism is being bombarded incessantly with facts, whose sum total information content is zero. On the other hand, several wave lengths or facts may be called upon to interfere constructively, so that in a small space of extension Δx , a large local amplitude ("information") will develop if the spread in wave number Δk ($k = \frac{2\pi}{\lambda}$) is sufficiently large. Out of the babel of noise or constant chattering of neurons, a discrete information bit emerges. The "information" bit (it is a minimum uncertainty condition because brain likes to minimise uncertainty, whose unit is \hbar) is considered to be a discrete quantum object that *we have called an infon*. From a background of a very agitated noisy neural medium, one information quantum detaches itself almost by accident, a quantum particle that organism finds suddenly very precious to possess. Meaning out of a random sea of facts is an evolutionary event, revolutionary also, nothing less nothing more but this led to cognition. This may very well be an acceptable scenario to start with.

The fundamental postulate of this communication states that mind is a pure information space, is considered to be a quantum field and that any state vector describing mind can only be an information vector. *The Fock space of the mind can be described by $0, 1, 2, \dots, \infty$ bits of information living in Fock or occupation number states $\{m\}$ where $m = 1, 2, 3, \dots, \infty$. These information quanta we shall call infons in analogy to electron or phonon or photon. We shall use the Dirac bra, $\langle A|$ or ket $|A\rangle$ notations to designate Hilbert space vectors for example the vector A [22].*

The infons are considered to be identical. This is so if and only if they are excitations of the same underlying field. The often asked question "why all electrons are identical" arises from mistakenly regarding individual electrons as fundamental objects, when in fact it is the underlying electron field that is fundamental. The same is true of infon particles with respect to the underlying field which we call our mind. Quantum mechanics, in its most general formulation, is a theory of abstract operators (observables) acting on an abstract state space (Hilbert space), where the observables represent physically observable quantities and the state space represents the possible states of our system. Each observable can be taken as a possible degree of freedom. A classical field contains only a limited number of degrees of freedom (a classical electromagnetic field has only two, local electrical and magnetic field vectors). A quantum field has unlimited, possibly infinite degrees of freedom. For our cognitive system, the observables are the different cognitive functions, in principle there are an

unlimited number of them. We shall work in grand canonical ensemble, where number of these fundamental excitations $\{m\}$ will be allowed to vary. These give rise to different functions in the mental space as quantum superpositions of various Fock numbers $\{m\}$; they form the function states $\{\alpha\}$ that live and that the organism conserves. Each function state is an eigenstate meant to preserve the required brain function through one's whole life. The highest energy functional state is the cognition whose ground state representation we shall now construct. Phase coherence between infon particles which in turn gives rise to inter-functional coherence is a result of constructive interference between infon particles. This would not happen if these were classical particles which never interfere and where each go their own way. It is in this inner sense that mental space can be considered as a quantum field.

We can describe the mental field in two ways. Either in terms of mental state wave functions in the Fock space $|\Psi_\alpha\rangle$ where $\{\alpha\}$ is the label of a whole collection of states that are expected to be grouped into distinct cognitive functions $\{\alpha, \beta, \dots\}$ as defined below. Or we go out of the Fock space and define the mental space in terms of neuronal wave functions $|i\rangle$ where $\{i\}$ is the label of a collections of cortical synapse sites i . Each group of some $\{i\}$ is presumed to be responsible for some particular function α . We insist on the cortical location of these synapses which we consider to be the seat of Cognition and eventual phenomenon of consciousness. Eventually a cognitive program or *engram* will emerge which is an information code in the synapse. The information that brain generates is useful only if it is associated with some *program*, $\{p_\alpha\}$.

In the mental functional space without referring to neurons, *the shortest program one can conceive of is zero information state $|0\rangle$* . No information would be comprehensible without presence of this state. The space between two written words or the silence between two musical notes or the empty space between two strokes of colour makes all the difference between meaning and meaninglessness. Next must be a single information bit containing just one quantum $|m=1\rangle$; this is like the letter *A* or *I* of the English alphabet, comprising the two shortest words of the language. In general we need a string of infons $\{m\}$ to compose a program, strung together in some coherent order, for it to make a sense. To get an idea of what we call a program, let us distribute m number of infons (where m goes from 0 to N) over the different cognitive functions $\{\alpha\}$ where α goes from 1 to M . If we assume that there is no restriction of number of infons that can reside in any single function α , then the number of distinct ways or complexions we can arrange the m_α infons amongst p_α programs is given by the Bose-distribution [23]

$$p(m_\alpha) = \frac{(m_\alpha + p_\alpha - 1)!}{m_\alpha! (p_\alpha - 1)!} \quad (1)$$

As an example, if we take the visual function, where we need to have programs to, see the colours of the object, its location in space, the different contrasts of light intensity for a given object, speed and direction of its motion, to name at random just a few. The actual act of seeing must integrate all these sub-functions rapidly with minimum uncertainty. We need a whole set of programs

covering all energy channels, to execute a *function* α . We can define a coherent cognitive function α , *through sets of programs from each energy channel* $p(m_\alpha)$ as

$$|\Psi_\alpha\rangle = \sum_{m_\alpha=0,1,\dots}^{\infty} a_m(\alpha) |m_\alpha\rangle \quad (2)$$

The probability amplitude $a_m(\alpha)$ which is a complex number is the weight of each state $|m_\alpha\rangle$ in the cognitive function α and is given by

$$|a_m(\alpha)|^2 = \frac{p_m^\alpha}{p_m}$$

We have

$$\begin{aligned} N &= \sum_{\alpha} m_\alpha \\ \sum_{\alpha} p_m^\alpha &= p_m \end{aligned}$$

The a_m^α is a string of information bits m that we need for some function ; a single information bit carries no meaning. The information content of α, β, γ etc are the different cognitive genetic codes (different from the ones involved in the autonomous nervous functions like respiration, heart rhythm control etc that do not depend on the cortex). Many of these essential autonomous functions are like deep quantum levels for the information bits and resemble orbital core states. Those automatic nervous functions are stationary energy states like molecular orbital states. In these states the information current is going round and around as in electron orbitals in an atom, without dissipation, lasting a life time; they form our daily automatism. These functions constitute sturdy energy levels that normal outside events do not easily perturb, unless some violent events occur.

Cognitive functions belong in this hierarchy of energy states to the highest energy level ϵ_c that the infons can occupy. Continuing the upward chain of functional hierarchy, several cognitive functions (vision, smell, sound etc) bunch together coherently to perform a *task*. Two tasks can mutually interfere just as two classical light beams through two slits, showing the double nature of infons: particles and wave just as light does in the two beam experiment. The interference shows up as the difficulty often encountered to be attentive to two cerebral tasks at the same time.

System will choose a certain set of complexions to constitute the required function which could be vision or taste or memory or feeling. All of them will constitute the ground or equilibrium state of the mind. We will show later on that consciousness is a property of excited state of the cognitive system. In the ground state one has no consciousness. We cannot have any idea what functions will emerge in the brain of a dinosaur or a shrimp, so numerous are the possible programs or the synaptic complexions. We shall never know what it feels to be a bat ! Hence the question " What is it like for bats to sense objects by echolocation ?" must remain unanswered [24] The functional aspect of the program

is tied to the distribution of infons around the synaptic sites. If certain synaptic sites are never occupied the program will wither away. And if certain function is rarely performed, the given synaptic connection may dissolve altogether; one or some of the terms of p_m will not contribute. This may happen within the life time of the individual. New functions can emerge as part of the learning process or over a longer period, like the function of writing that did not exist until several thousand years ago. The information space that constitutes the Hilbert space of the mind is a functional space and is inoperative without the neurons. This Function space constitutes the Cognitive quantum field that will be used to construct a coherent brain state.

2.1 Self Operators and Coherent Brain State

Let us introduce non-hermitian operators, that we have christened *self operators*. It carries the instruction to fabricate information like particles in mental space, responsible for *information field and our mental life*. *Self* is the expression of our genetic identity that affirms wherever and whenever it is needed, the uniqueness of the individual. The self operator s_α and its Hermitian conjugate s_α^\dagger has the property of destroying one infon or creating an infon in the function state $|1_\alpha\rangle$ respectively *out of the mental vacuum* $|0\rangle$. This is formally written as the operation

$$\begin{aligned} s_\alpha^\dagger |0\rangle &= |1_\alpha\rangle \\ s_\alpha |1_\alpha\rangle &= |0\rangle \end{aligned} \tag{3}$$

Repeated application of the infon operators will generate all the vectors of $\{\alpha\}$ such as

$$\begin{aligned} s_\alpha^\dagger |1_\alpha\rangle &= \sqrt{1} |2_\alpha\rangle \\ s_\alpha |2_\alpha\rangle &= \sqrt{2} |1_\alpha\rangle \end{aligned}$$

This is standard boson operator algebra; the operators are known as ladder operators since they increase or decrease the occupation number of a state vector by just one every time they are applied on a ket vector. Any standard quantum mechanics text book can be consulted for details. From this fundamental basic operators defining operations involving infons in the full mental Hilbert space, we can go on and define operators in the Function space $\{\alpha\}$ (which is a truncated Hilbert space), through the operation

$$|\Psi_\alpha\rangle = \sum_m a_m(\alpha) |m\rangle_\alpha \tag{4}$$

The states $\{m\}$ are the independent linear orthogonal vectors of Fock space defining the Hilbert space of mind while the orthogonal linear vectors $|m_\alpha\rangle$ constitute the mental subspace of cognitive functions. The operators $\{s_\alpha\}$ are initiators of cognitive functions and are instruction protocols like all operators

in quantum mechanics. Neurons are the conduits of mental action, not the otherway around. Cognitive functional space $\{\alpha\}$ is to neurons what cyber space is to the electronic hardware comprising a computer.

The ensemble of representations $\{|\Psi_\alpha\rangle\}$ constitutes the abstract space on which our whole mental life will be constructed. All of the cognitive functions are real, hence they belong to a Hilbert space. All reality, that which is measurable (factual, Hermitian) and that which is non-measurable (but no less real), like pain or pleasure (emotional, non-Hermitian) comes out from this space. These fundamental self operators (there are exactly three of them) are considered to constitute the back bone of cognition system and have the following properties :

1. Besides the creation operator s_α^\dagger , we have its conjugate twin, the corresponding destruction operator s_α that has the instruction to destroy an existing infon in the function α , thereby decreasing number of infons already existing in the state $|\Psi_\alpha\rangle$ by one. By definition vacuum state itself is annihilated by its action $s_\alpha|0\rangle = 0$, for all α .
2. The combined action of these two operators is the third operator, called preservation or number operator and helps count the total number of infons in a given neuron, when it operates on that state.

$$s_\alpha^\dagger s_\alpha = n_\alpha$$

To emphasise the operator character of the number operator n we have

$$n_\alpha|i\rangle = p_\alpha|\alpha\rangle \quad (5)$$

This operation or measurement gives us the total number of information like particles in the function α . The creation and the destruction operators are taken to be non-hermitian while n_α is hermitian.

3. We consider the infons as Bose particles. In contrast to Fermions which occupy a spot in space, only one at a time (in the absence of spin), Bosons have the advantage that they can be generated at any space as many as one wants by repeated application of the creation operator on vacuum. Any number p_α of *infons* can crowd into any single function $|\Psi_\alpha\rangle$.
4. The different functions $\{\alpha\}$ commute. Translated into simple language, it means that any number of cognitive functions can be measured (felt) simultaneously. We write this as Bose commutation relationships [25]

$$[s_\alpha, s_\beta] = [s_\alpha^\dagger, s_\beta^\dagger] = 0 \quad (6)$$

$$s_\alpha^\dagger(x), s_\beta(x') = \delta_{\alpha\beta}\delta_{xx'} \quad (7)$$

The first set of relationships tell us that those pair of operators commute at equal time and that their actions are simultaneously measurable. Because they

commute, they are independent and do not interfere with each other. We will show below that this equal time commutability proceeds from the fact that the set of operators $\{s_\alpha\}$ generate their individual eigen values when they operate *on the same coherent wave function*. The second set of relationships imply that any two operators $\{s_\alpha^\dagger(x), s_\beta(x')\}$ are orthogonal .

To get a coherent wave function signifying the coherent brain state, let us first focus on just one single cognitive function α . The defining function state for $|\Psi_\alpha\rangle$ shows that a varying population of infons m is needed for each function α . The coherent Glauber state of infons is written as the wave function $|\Psi_\alpha\rangle$, as [26]

$$|\Psi_\alpha\rangle = \sum_{m=0,1,2,\dots} a_m(\alpha) |m\rangle_\alpha \quad (8)$$

The significant aspect of this wave function is the possibility that at any given time there can be any number of infons in the function α ; the $a_m(\alpha)$ are complex coefficients. If we choose these coefficients judiciously, then the different probability amplitudes $a_m(\alpha)$ of each of the Fock state $|m\rangle$ will add up constructively to give a macroscopic amplitude of infons only if they have a common phase angle θ_α . When this happens we shall get the coherent state $|\Psi_\alpha\rangle$.

An exactly equivalent formulation of the Glauber state, can be given explicitly in terms of s_α^\dagger . The coherent state, in the zeroth order is given by the exponential operation

$$|\Psi_\alpha\rangle = \exp(\phi_\alpha s_\alpha^\dagger) |0\rangle \quad (9)$$

Here although it is not visible yet, the expression has the parameter ϕ_α which will turn out to be the hidden cognitive order of the function α . This state has the expansion

$$|\Psi_\alpha\rangle = |0\rangle + \phi_\alpha s_\alpha^\dagger |0\rangle + \frac{(\phi_\alpha s_\alpha^\dagger)^2}{2!} |0\rangle + \dots \quad (10)$$

This expansion shows that the coherent state is made out of varying number of infons. To understand the coherent state, we may write the operator expression

$$s_\alpha(\phi_\alpha) = \exp^{-\phi_\alpha s_\alpha^\dagger} s_\alpha \exp^{\phi_\alpha s_\alpha^\dagger} = s_\alpha + \phi_\alpha \quad (11)$$

We see that the action of the exponential operator is to translate the destruction operator by a complex number ϕ_α . This gives the key property of the coherent state as being the eigenstate of the destruction operator

$$s_\alpha |\Psi_\alpha\rangle = \exp^{\phi_\alpha s_\alpha^\dagger} \exp^{-\phi_\alpha s_\alpha^\dagger} s_\alpha \exp^{\phi_\alpha s_\alpha^\dagger} |0\rangle = \phi_\alpha |\Psi_\alpha\rangle \quad (12)$$

This result follows when we use the fact $s_\alpha |0\rangle = 0$. The result also shows that ϕ_α is the eigenvalue of the destruction operator. Since s_α is a non-hermitian operator, the eigenvalue can only be complex. This result points out that the operator average $\langle s_\alpha \rangle$ is precisely ϕ_α .

$$\langle \Psi_\alpha | s_\alpha | \Psi_\alpha \rangle = \phi_\alpha \quad (13)$$

That the complex parameter ϕ_α is in reality an order parameter can be seen from

$$\langle \Psi_\alpha | n_\alpha | \Psi_\alpha \rangle = \langle \Psi_\alpha | s_\alpha^\dagger s_\alpha | \Psi_\alpha \rangle = \phi_\alpha^* \phi_\alpha = \langle N_\alpha \rangle$$

Since $\langle N_\alpha \rangle$ is just a number, number of infons on an average involved in the function α , we can write down the order parameter as a complex scalar quantity

$$\phi_\alpha = \sqrt{\langle N_\alpha \rangle} \exp i\theta_\alpha$$

The different functions $\{\Psi_\alpha\}$ are *distinguishable*. Although the electrical signals coming through the neurons are all alike to start with, what ultimately distinguish them one from the other is the response they provoke in the different sensory channels. The global coherent state due to all $\{\Psi_\alpha\}$ functions can now be written down. For all these functions we can write for the global coherent cognitive wave function, the product wave function

$$|\Psi_C\rangle = \Pi_\alpha |\Psi_\alpha\rangle \quad (14)$$

This can be expanded as

$$|\Psi_C\rangle = \Pi_\alpha \exp(\phi_\alpha s_\alpha^\dagger) |0\rangle = \exp^{\sum_\alpha (\phi_\alpha s_\alpha^\dagger)} |0\rangle = \exp^{S^\dagger \Phi_C} |0\rangle \quad (15)$$

We have written Φ_C as a $v \times 1$ column matrix

$$\Phi_C = \begin{pmatrix} \phi_\alpha \\ \phi_\beta \\ \dots \\ \phi_v \end{pmatrix} \quad (16)$$

We also write global creation operator S^\dagger as a $1 \times v$ row matrix

$$S^\dagger = (s_\alpha^\dagger \dots s_v^\dagger)$$

Then we have

$$S^\dagger \Phi_C = \sum_{\alpha, \dots, v} s_\alpha^\dagger \phi_\alpha$$

This allowed us to write as we did the global coherent state

$$|\Psi_C\rangle = \exp^{S^\dagger \Phi_C} |0\rangle$$

The coherent state $|\Psi_C\rangle$ has the nice property of being able to single out a given function order parameter when it is acted upon by the function field operator s_α .

$$s_\alpha |\Psi_C\rangle = \phi_\alpha |\Psi_C\rangle$$

The global cognitive wave function $|\Psi_C\rangle$ allows simultaneous measurements in all functional channels α and this is why these operators $\{s_\alpha\}$ commute.

we can write for the global order parameter Φ_C

$$\Phi_C^* \Phi_C = \frac{1}{M} \sum_{\alpha} \Phi_{\alpha}^* \Phi_{\alpha} = \frac{1}{M} \sum_i \langle N_{\alpha} \rangle = \frac{N_C}{M} \quad (17)$$

Here N_C is the global average information population in *the cortical brain* summed over all the cognitive functions, M . Now a global cognitive order parameter Φ_C has emerged with one single phase θ_C to signify over-all phase coherence of the information field. Expression of equation 17 allows us to write for the global cognitive order in the form

$$\Phi_C = \sqrt{\frac{N_C}{M}} \exp i \theta_C \quad (18)$$

There are several key points we would like to make at this stage:

(a) To obtain the global order, we have summed over all neuron labels. This emphasises the fact that the cognitive order parameter Φ_C represents in reality the full mental landscape. The individual label and phase of each neuron has disappeared from the global cognitive order which has emerged with its own global phase θ_C *independent of space and time*.

(b) The global order parameter can be defined as the operator average of the global destruction operator of self S which we write as

$$\Phi_C = \langle \Psi_C | S | \Psi_C \rangle \quad (19)$$

Here S is the column matrix representing destruction operators

$$S = \begin{pmatrix} s_{\alpha} \\ s_{\beta} \\ \dots \\ s_v \end{pmatrix}$$

Since S is one of the three matrix elements of *Self*, we take the bold step to call this order parameter \mathcal{I} . We make the identification

$$\Phi_C = \mathcal{I} \quad (20)$$

Now the self operator has taken a macroscopic significance. **" \mathcal{I} am" has emerged as a result of global phase coherence between N_C information bits. The meaning of the global cognitive order is \mathcal{I} . This phase coherence is brought about by more and more rapid information transfer through synaptic connections between neurons. A critical neuron band-width or connectivity must occur before, \mathcal{I} can emerge.**

(c) The unique global phase angle θ_C for Φ_C with which order parameter emerges is a symmetry breaking transition. Any other θ would have been equally good from the point of view of total energy of the cognitive system, but this θ_C and only this one, the order parameter Φ_C of the brain system has chosen and retains throughout one's whole life. We have named this \mathcal{I} , precisely because

this unique θ_C confers on each individual his individuality, the imprint of an unique personality. The subjective *self* given by $\langle S \rangle$ breaks the symmetry of the mental space $\{m\}$; a subjective-objective symmetry so to speak. From this point onwards, *self* and *self-consciousness* emerge as the hallmark of a stable personality.

(d) Mathematically the unique global phase θ_C , translates the fact that the infon population N_C is a variable number and the coherent brain ground state $|F_C(\theta)\rangle$ that fixes θ can be expressed in the form

$$|\Psi_C(\theta)\rangle = \sum_{N_C} \Psi(N_C) \exp iN_C\theta_C \quad (21)$$

$$\Delta N_C \Delta \theta_C \sim 1 \quad (22)$$

The uncertainty relationship between phase locking of the global wave function and its information content is fundamental to the coherency of all brain processes. We must allow this number to fluctuate if we are to have a macroscopic coherent cognitive state.

2.2 Synaptic Self and Spontaneous Symmetry Breaking

In the preceding section we have constructed a globally coherent cognitive state $|\Psi_C\rangle$ associated with the cognitive order parameter Φ_C that we have called the first person \mathcal{I} . We have worked entirely in the mental landscape defined by its diverse cognitive functions. Everything was done as if outside world did not exist. But developing coherent cognitive functions in the absence of interaction with outside world is as useless as developing an alphabet or language that no one would use. As a matter of fact, one suspects that the cognitive functions that would survive are precisely those that help us to cope with the world in a Darwinian sense.

The world connects to the mind through our neurons. Mind also expresses itself through the same neuron network. Thus the neuron is the go-between mind and world, a window for the mind within and for the world without. Neurons connect with other neurons through the synaptic sites. While just before a baby is born, neurons are being created at the astonishing rate of 250,000 neurons per minute, right after birth synaptic connections between those neurons are being made at the astronomical rate of several million connections per second! [27]. One can make a strong case that synaptic connections are essential for information transfer between different regions of brain and that synaptic sites may well be where infons are stored. At least this is the view we shall adopt.

We shall introduce field operators of self ψ_i connected with info creation at synaptic sites, i . The corresponding creation operator is ψ_i^\dagger which when operates on the vacuum state creates one infon in the state vector $|1_i\rangle$. We write

$$\psi_i^\dagger |0\rangle = |1_i\rangle \quad (23)$$

The local field operators ψ_i can be written in terms of the internal function

space basis operators s_α

$$\psi_i = \sum_{\alpha} \phi_{\alpha}(i) s_{\alpha} \quad (24)$$

And similarly for ψ_i^\dagger . Here $\phi_{\alpha}(i)$ is a complex probability amplitude of finding the projection of the mental state α on the synaptic site i . We can obtain the average value of the synaptic site operator $\langle \psi_i \rangle$ by using the cognitive wave function 14

$$\langle \psi_i \rangle = \langle \Psi_c | \psi_i | \Psi_c \rangle \quad (25)$$

To illustrate, suppose we have a Ψ_c composed of just two cognitive functions α and β .

$$\text{Then we have for the wave function } \Psi_c = \begin{pmatrix} \Psi_{\alpha} \\ \Psi_{\beta} \end{pmatrix}$$

$$\langle \psi_i \rangle = [\Psi_{\alpha}^* \ \Psi_{\beta}^*] \begin{bmatrix} \psi_i^{\alpha\alpha} & \psi_i^{\alpha\beta} \\ \psi_i^{\beta\alpha} & \psi_i^{\beta\beta} \end{bmatrix} \begin{bmatrix} \Psi_{\alpha} \\ \Psi_{\beta} \end{bmatrix}$$

Here $\psi_i^{\alpha\alpha}$ is , $\langle \Psi_{\alpha} | \psi_i | \Psi_{\alpha} \rangle$ and similarly for the other matrix elements.

This is rewritten as

$$\langle \psi_i \rangle = \begin{bmatrix} |\Psi_{\alpha}|^2 & \Psi_{\alpha} \Psi_{\beta}^* \\ \Psi_{\beta} \Psi_{\alpha}^* & |\Psi_{\beta}|^2 \end{bmatrix} \begin{bmatrix} \psi_i^{\alpha\alpha} & \psi_i^{\alpha\beta} \\ \psi_i^{\beta\alpha} & \psi_i^{\beta\beta} \end{bmatrix}$$

This can be also written as

$$\langle \psi_i \rangle = \text{trace } (\rho \psi_i)$$

The infon density matrix ρ (which is a $M \times M$ square matrix) has the usual definition

$$\rho = |\Psi_c\rangle \langle \Psi_c| = \begin{bmatrix} \Psi_{\alpha} \\ \Psi_{\beta} \\ \vdots \\ \text{etc} \end{bmatrix} [\Psi_{\alpha} \ \Psi_{\beta} \dots \text{etc}]$$

Now we are in a position to define global synaptic self average Φ_s as

$$\Phi_s = \begin{bmatrix} \langle \psi_i \rangle \\ \langle \psi_k \rangle \\ \langle \psi_l \rangle \\ \text{etc} \end{bmatrix} \quad (26)$$

We impose global synaptic self average to be the same as the cognitive functional average and equate both to I . We write $I = \Phi_c = \Phi_s$. This implies

$$|\Phi_c|^2 = |\Phi_s|^2 = \sum_i |\langle \psi_i \rangle|^2 = \sum_i n_i = N_c$$

The statement made just above is capital. *It says what goes in the mind goes in the synapses; there is no way to distinguish our cognitive self as epitomised by I from our synaptic self.* [27].

As the order parameter develops in the ground state, long range correlation develops between local order between different synaptic sites, say i & j . If the distance between i & j goes to ∞ but correlation $\langle \psi(i) \psi^*(j) \rangle$ remains finite, then we have a genuine Bose condensation [23] in human brain. Because of the finite dimension of our system this is impossible to have. A less restrictive condition of having something like a bose-condensate is to rewrite this correlation in an alternate form. We write

$$\begin{aligned} \langle \psi(i) \psi^*(j) \rangle &= \left\langle \sum_{\alpha} \phi_{\alpha}(i) s_{\alpha} \sum_{\beta} \phi_{\beta}^*(j) s_{\beta}^{\dagger} \right\rangle \\ &= \sum_{\alpha, \beta} s_{\alpha} s_{\beta}^{\dagger} \langle \phi_{\alpha}(i) \phi_{\beta}^*(j) \rangle \\ &= \sum_{\alpha} N_{\alpha} \langle \phi_{\alpha}(i) \phi_{\alpha}^*(j) \rangle \end{aligned} \quad (27)$$

Here we have used the commutation properties of the operators $s_{\alpha}, s_{\beta}^{\dagger}$ etc introduced in the last section. This is off-diagonal information correlation between two different synaptic sites and can have a macroscopic value if the condensate density N_{α} develops in one of the functional channels. This is closest we shall get to a bose-condensed state in these inhomogeneous finite size systems.

The coherent cognitive state is a symmetry broken state, as we explained in the last section. Let us be a little more specific.

There is a whole general class of systems that show spontaneous symmetry breaking in their ground state while their dynamics (hamiltonian) is invariant of that symmetry[28]. The ferromagnet is a familiar example: its global magnetisation chooses to lie in an arbitrary direction, while it could have chosen any other direction without any extra energy cost. Superfluid He or Superconductors are other examples from condensed matter physics, where the order parameter chooses a global unique phase while its free energy does not depend on that phase angle. In our case the cognitive order parameter does the same although we do not know the exact nature of the hamiltonian H_0 that we need to describe the dynamics or evolution of the information field. What we need to note is that the coherent cognitive wave function $|\Psi_C\rangle$ and its associated order parameter Φ_c were constructed by repeated action of the self operator on the vacuum state $|0\rangle$. This $|0\rangle$ is nothing but the bare inherited genetic magma from the very instant that the child was conceived. There was no reference to the world as yet. We need to confront this order parameter to the world which the new born baby will face. It is convenient to introduce the world as some external perurbation H' to see if the unique ground state $|\Psi_C\rangle$ engendered by H_0 remains intact in the absence of the perturbation as we go to the limit of no world. This is extremely relevant since everyday we go to this limit when we fall asleep and every time we do so we need to recover the same unique ground

state $|\Psi_c\rangle$ with the cognitive order \mathcal{I} .

Let us write the total hamiltonian governing the cognitive brain as

$$H = H_0 + H' \quad (28)$$

The perturbation due to world (this includes interaction with one's own body) is written as

$$H' = \sum_i \eta_i \left[\psi_i \Omega_i^* + \psi_i^\dagger \Omega_i \right] = \sum_i \eta_i H'_i \quad (29)$$

Here the world designated by Ω_i acts at the synaptic site i locally with the operator ψ_i through some suitable coupling constant η_i . We assume that the main part of the Hamiltonian H_0 had done its job in creating the unperurbed ground state $|\Psi_C\rangle$, with a corresponding ground state energy E_C , which is the lowest energy of the coherent cognitive state, of the brain at repose. Due to coupling η , both the ground state wave function as well as the state energy will be shifted to $|\Psi_C(\eta)\rangle$ and $E_C(\eta)$. Let us call the new total hamiltonian by $H(\eta)$ and write

$$E_C(\eta) = \langle \Psi_C(\eta) | H(\eta) | \Psi_C(\eta) \rangle \quad (30)$$

The change in ground state energy can be written as (due to a trick first used by Pauli)

the so called coupling constant integration

$$\Delta E_C = E_C(1) - E_C(0) = \sum_i \int_0^1 d\eta_i \langle \Psi_C(\eta_i) | H'_i | \Psi_C(\eta_i) \rangle \quad (31)$$

This perturbation generates a new operator average $\langle \psi_i \rangle$ that we can write as

$$\langle \psi_i \rangle = \frac{\partial (\Delta E_C)}{\partial \Omega_i} = \int_0^1 d\eta_i \left\langle \Psi_C(\eta) \left| \frac{\partial H'_i}{\partial \Omega_i} \right| \Psi_C(\eta) \right\rangle \quad (32)$$

We do this integration by seperating it into two parts as

$$\langle \psi_i \rangle = \left\langle \Psi_C(0) \left| \frac{\partial H'_i}{\partial \Omega_i} \right| \Psi_C(0) \right\rangle + \int_{\eta \neq 0}^1 d\eta_i \left\langle \Psi_C(\eta) \left| \frac{\partial H'_i}{\partial \Omega_i} \right| \Psi_C(\eta) \right\rangle$$

If the first term of the right hand side survives even in the absence of coupling to the world then we have a symmetry broken ground state given by the local cognitive order parameter average $\langle \psi_i \rangle_0$. We can then write

$$\langle \psi_i \rangle = \langle \psi_i \rangle_0 + \delta \langle \psi_i \rangle_0$$

The sources or the 'world' Ω & Ω^* were introduced in order to select a unique equilibrium state—so as to set the 'alignment' of the cognitive system just as a magnetic field does for the ferromagnet. These sources induce non-vanishing values of the field operators, $\langle \psi_i^\dagger \rangle_0$ and $\langle \psi_i \rangle_0$. For a normal system that does

not show spontaneous symmetry breaking, these field expectation values vanish when the sources are turned off. But in a symmetry broken state, this does not occur. The non zero operator averages remain intact even when there is no external source. This result shows us that Φ has the broken symmetry : $\Phi \rightarrow \Phi_o$ even when the world $\Omega \rightarrow 0$. *Translated into more mundane cognitive terms, this says that as we fall asleep, the world $\Omega \rightarrow 0$ but the cognitive order parameter, \mathcal{I} returns to the base value, characterising the equilibrium ground state. World is lost during sleep, but not \mathcal{I} .*

N_o and θ are conjugate quantities. This is exemplified by the uncertainty relationship

$$\Delta N_o \Delta \theta \succeq 1$$

The simple reason that phase and particle number are conjugate quantities imply that their simultaneous measurement is limited by the Heisenberg uncertainty principle. Consequently, boson like particles can either be in an eigenstate of particle number or of phase. The eigenstate of particle number means a system with fixed population of infons, and is a localised state or a neuron with no connection to other neurons. This phase can be called *a-state*. The second state of the information system, named *b-state* is the one where the information is fluid but the phase coherence has very short range in space and time. This is a mixed state, neither localised nor completely fluid, at best is an incoherent mixture of the two and is not an eigenstate. The eigenstate of phase is a superfluid. This is the state where information particles live and move coherently from synapse to synapse. This state we will call the *state c*. We can characterise each of these states by

$$\begin{aligned} \langle \exp i\theta_i \rangle &= 0, \text{ state } a \\ \langle \exp i\theta_i \rangle &\neq 0, \quad \langle \exp i(\theta_i - \theta_j) \rangle = 0 ; \text{ state } b \\ \langle \exp i(\theta_i - \theta_j) \rangle &\neq 0, i - j \rightarrow \infty, \text{ state } c \end{aligned}$$

Here i and j are neuron positions.

We can think of *a-state* as belonging to worms or single cellular creatures possessing a few or no neurons to speak of. *b-state* can be expected to belong to babies, less than 2 yrs old and higher domestic animals, creatures that are perfectly conscious but not of themselves ;there is, as yet no long range phase coherence, conscious experience is there but is fragmented. There may be a ghost of \mathcal{I} but it is more like the smile of a cheshire cat ! In the *c-state*, long range phase correlation between neurons are firmly established and brain has entered its coherent state; that of adult human brain. Penrose [39] had posed the question whether a one cellular creature like a paramecium or a bacterium (which does not even have a neuron) can have consciousness? Our answer seems to be quite unambiguous— it cannot. It lives in the state α (neuron or no neuron), no order parameter can form locally ; even if it did, phase and amplitude fluctuation will kill all coherence as it invariably does in one dimensional systems. A 2-yr old baby possesses already an \mathcal{I} and recognises himself in the mirror. From $\mathcal{I}=0$ at birth, the individual has gone to the free

energy minimum of $\mathcal{I} \neq 0$, all due to the tremendous explosion in synaptic connectivity in those first two years after a child's birth. These three states mimic closely condensed phase of bosonic systems, namely, localised insulting state, disordered boson glass phase & symmetry broken superfluid phase , a, b & c phases respectively [40].

2.3 Thermodynamics of Cognitive Order

To make some of these ideas more quantitative, we express the Hamiltonian H of $M - neurons$, in two parts, a part which is internal to the brain system, H_o and a part that brings about perturbation due to interaction of the infons with the world, H' . We consider that in the absence of the world, the cognitive system develops the coherent order parameter Φ_C , called now Φ_C^o to indicate that it is the unperturbed ground state, engendered by H^o .

Let us write the partition function to obtain the relevant thermodynamic quantities to obtain the equilibrium order parameter as an extremum of Hemholtz free energy and see how this shifts in the presence of H' . We introduce real time t but this symbol can also be replaced by imaginary time if we have to. We write the perturbation due to external world as

$$H' = \int dt \int dr_i \left[\psi_i^\dagger(t) \Omega(i, t) + \psi_i(t) \Omega(i, t) \right]$$

We also have used

$$\psi(i, t) = \exp^{iH_o t} \psi_i(o) \exp^{-iH_o t}$$

Here H_o is the unperturbed original hamiltonian that we have not specified so far. We can write for the grand partition function through functional integration

$$Z[\Omega, \Omega^*] = \int [d\psi_i] [d\psi_i^*] \exp \left\{ \int dt L + \int dt \int dr \left[\begin{array}{c} \psi_i^*(t) \Omega(r, t) \\ + \psi_i(t) \Omega^*(r, t) \end{array} \right] \right\} \quad (33)$$

Here L is the Lagrangian given by

$$L = H_o - i \int dr_i \psi_i^*(t) \frac{\partial}{\partial t} \psi_i(t) \quad (34)$$

Here we have replaced the operators ψ and ψ^\dagger by functional integration variable ψ and ψ^* . In this formulation the self operators are integrated away and the partition function is expressed only in terms of the world. The effective action or Helmholtz free energy is given by

$$F[\Omega, \Omega^*] = \ln Z[\Omega, \Omega^*] \quad (35)$$

By simple differentiaion we get

$$\begin{aligned} \frac{\partial F[\Omega, \Omega^*]}{\partial \Omega(i, t)} &= \frac{1}{Z} \frac{dZ}{d\Omega(i, t)} = \langle \psi_i^\dagger(t) \rangle \\ \frac{\partial F[\Omega, \Omega^*]}{\partial \Omega^*(i, t)} &= \frac{1}{Z} \frac{dZ}{d\Omega^*(i, t)} = \langle \psi_i(t) \rangle \end{aligned} \quad (36)$$

To see this clearly, it is convenient to consider the expectation values of $\langle\psi_i^\dagger(t)\rangle$ and $\langle\psi_i(t)\rangle$ as the independent variables (rather than the sources Ω & Ω^*) by carrying out a functional Lagrange transformation which defines the Gibb's potential Λ

$$\Lambda = \int dt \int dr_i [\psi_i^*(t)\Omega(i, t) + \psi_i(t)\Omega^*(i, t) - F[\Omega, \Omega^*]] \quad (37)$$

Consider variation of this equation with respect to Ω & Ω^\dagger . We obtain

$$\partial\Lambda = \int dt \int dr_i \left\{ \partial\langle\psi_i^\dagger\rangle\Omega + \Omega^*\partial\langle\psi_i\rangle \right\}$$

Rest of the terms give zero. Thus we may regard Λ as a functional of $\langle\psi\rangle$ and $\langle\psi^\dagger\rangle$. This gives us

$$\begin{aligned} \frac{\partial\Lambda[\langle\psi\rangle, \langle\psi^\dagger\rangle]}{\partial\langle\psi^\dagger(i, t)\rangle} &= \Omega(i, t) \\ \frac{\partial\Lambda[\langle\psi\rangle, \langle\psi^\dagger\rangle]}{\partial\langle\psi(i, t)\rangle} &= \Omega^*(i, t) \end{aligned} \quad (38)$$

These derivatives give us a functional definition of external world parametrised by Ω . We can go to an external world which is constant in space and time, $\Omega(i, t) \rightarrow \Omega$ and $\Omega^*(i, t) \rightarrow \Omega^*$. In this case the expectation values of the field operators must also be constant. Now, we can write the extensive Gibb's potential in the intensive form

$$\Lambda = \beta VG(\langle\psi_i\rangle, \langle\psi_i^\dagger\rangle) \quad (39)$$

Here G is Gibb's free energy per unit volume and V is the volume of the system. Let us a global cognitive field order parameter as

$$\langle\psi_i\rangle = \langle\Psi\rangle = \Phi$$

In the limit of sources uniform locally over each neuron, we have

$$\begin{aligned} \frac{\partial G(|\langle\Psi\rangle|^2)}{\partial\langle\psi_i\rangle} &= \Omega_i^* \\ \frac{\partial G(|\langle\Psi\rangle|^2)}{\partial\langle\psi_i^\dagger\rangle} &= \Omega_i \end{aligned} \quad (40)$$

The correct thermodynamic state is determined as a stationary point of the effective potential or Gibb's free energy. At the equilibrium point $\langle\psi_i\rangle = \langle\Psi\rangle_{eq}$ we must have

$$\begin{aligned}
\left(\frac{\partial G(|\langle \Psi \rangle|^2)}{\partial \langle \psi_i \rangle} \right)_{\langle \psi_i \rangle = \langle \Psi \rangle_{eq}} &= 0 \\
\left(\frac{\partial G(|\langle \Psi \rangle|^2)}{\partial \langle \psi_i^\dagger \rangle} \right)_{\langle \psi_i^\dagger \rangle = \langle \Psi^\dagger \rangle_{eq}} &= 0
\end{aligned} \tag{41}$$

This expression is true at all extremum. This shows us immediately that at the minimum of the Gibb's free energy, which will determine the cognitive order parameter with it's unique symmetry broken state, the world Ω vanishes. When we remember from the last section that $\langle \Psi_c \rangle = \Phi_s = \mathcal{I}$, then we can draw the conclusion *that when we are in the equilibrium state of the cognitive sysem, the world vanishes. In full anaesthesia or in sleep \mathcal{I} remains perfectly intact and every time we wake up we do retrieve our \mathcal{I} .* This is the unambiguous demonstration that the brain lives in a spontaneous symmetry broken state, akin to many condensed state systems including superfluid.

From now onwards, we shall call the mental space containing the cognitive order parameter $\langle \Psi_c \rangle$, as an \mathcal{I} - *field*. The ground state of this field occurs where $\langle \Psi_c \rangle$ gives a free energy minimum. From a semiclassical point of view, $\langle \Psi_c \rangle$ can be considered as a field which interacts with itself through a potential (also called the Gibb's free energy function, $G(|\langle \Psi_c \rangle|^2)$ written in the Ginzburg-Landau form[32]

$$G(|\langle \Psi \rangle|^2) = \mathbf{A} |\Phi|^2 + \mathbf{B} |\Phi|^4 \tag{42}$$

Here $|\langle \Psi \rangle| = \Phi$, is the amplitude of the average of the order parameter which we have shown to be a complex quantity with an amplitude and a phase. Let us start from the non-symmetry broken phase, with a positive value of the parameter \mathbf{A} that gives the minimum at $|\Phi| = 0$. Eventually when the phase transition to a $|\Phi| \neq 0$ phase would occur, symmetry breaking will take place, fixing the phase once for all. This expression for Gibb's free energy will assure us a minimum of the free energy at $\Phi = \Phi_{eq}$ if the parameter \mathbf{A} is < 0 and if the coefficient of the fourth order term \mathbf{B} is > 0 . The nature of these curves is shown in Figure 2.

It is clear that the vital parameter that brings about this minimum is when \mathbf{A} changes sign from positive value where the minimum of cognitive order is zero to a negative value, when some non-zero value Φ_{eq} develops, which is the value at equilibrium given by $\left(\frac{\partial G}{\partial |\Phi|} \right)_{|\Phi| = |\Phi|_{eq}} = 0$. This ground state of the \mathcal{I} - *field* occurs at

$$\langle \Psi \rangle_{eq} = \sqrt{\frac{-\mathbf{A}}{\mathbf{B}}} \exp -i\theta \tag{43}$$

This ground state is infinitely degenerate in θ , lying as it does at the bottom of the so called Mexican hat potential defined by "a ring of minima" for whatever be the value of θ . If this phase angle θ can be arbitrarily chosen at each point in

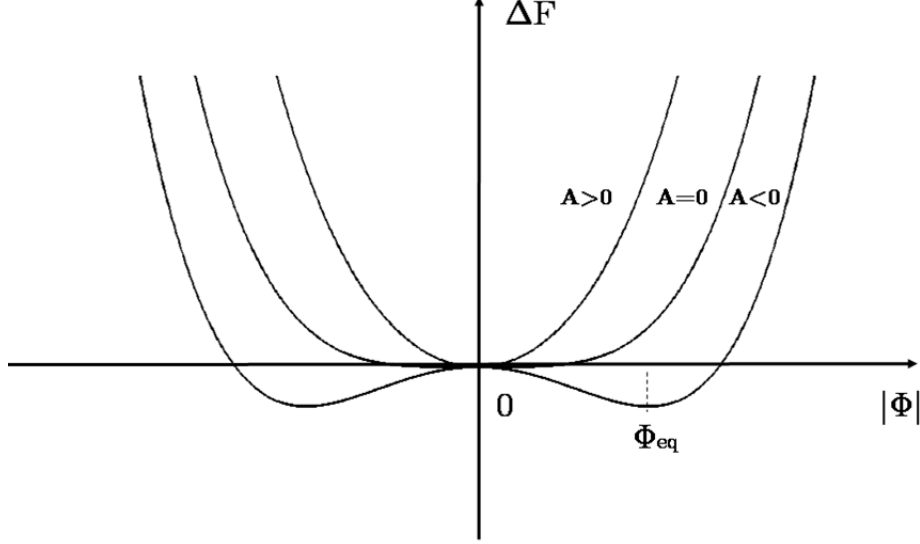


Figure 2: Free energy against amplitude of order parameter : $\mathbf{A} \succ \mathbf{0}$, babies \preceq 2 yrs; $\mathbf{A} = \mathbf{0}$, threshold of self; $\mathbf{A} \prec \mathbf{0}$, babies \succ 2 yrs, self \mathcal{I} formed

space and time, then the interaction of $\langle \Psi \rangle_{eq}$ with external world would move it continually as if $\langle \Psi \rangle$ were a free particle. But it is not ; it is a coherent state. The ground state of the system is required to be unique, so that phase must be fixed once for all, at all points of space and time. Thus symmetry breaking is self imposed to rid *self* of the tyranny of the outside world !

We know that a baby as born has no sense of self as yet and does not know who he or she is until at certain age ~ 2 years old. We also know that as as soon as a child is born, there is an explosion in his brain of synaptic connections, at the astonishing rate of \sim two millions/second, which is a measure of density of information flow from one neuron to its neighbors via its axon terminal (there are about 10^4 synaptic connections per neuron). The vital parameter \mathbf{A} is connected to this synaptic connectivity (*Appendix*). Beyond a critical value of synaptic connectivity \mathbf{A} becomes negative and all-important cognitive self can emerge as a coherent order parameter $\langle \Psi \rangle_{eq}$ or \mathcal{I} . We will sketch in the appendix a possible scenario of how it comes about.

The fluctuation out of the Mexican hat potential well and is governed by the coefficient of the second order term and gives \mathbf{A}

$$(\mathbf{A})_{\langle \psi \rangle = \Phi_{eq}} = \frac{1}{2} \left(\frac{\partial^2 G(\Phi^2)}{\partial^2 |\Phi|} \right)_{\langle \psi \rangle = \Phi_{eq}} \quad (44)$$

3 Cognitive Response

3.1 Cognitive Response and Consciousness

The problem of Consciousness is considered by many modern philosophers as the "hard problem" [29]. The Well known Australian philosopher Chalmers[30] details in a book why it is so hard and also which ones are easy problems; these include an objective study of the brain. In a more modest answer to some of these issues, that avoids erudite pitfalls, it is meaningful to *define consciousness as part of cognitive response of the brain to the world*. Having defined the ground state of the cognitive system as the \mathcal{I} -field, it seems sensible to ask what the excited state is like. The excitation comes when world presents itself and interacts with self operator. In the ground state where world is absent by construction, there is no world to couple with; there is no consciousness, as a result. Consciousness is one of the function of the excited state of the cognitive system. *it is a pure Response Function*. The problem is still hard but we have cleared a small space to work on and part of the problem becomes more tractable.

In this simple approach, we will couple external world designated by Ω to the global self operator Ψ^\dagger , where Ω is considered to be an infinite source and sink of information. Here Ψ and Ω are matrices $\{\psi_i\}$ and $\{\Omega_i\}$. We define cognitive response χ as response of the brain to perturbation H' due to external world. We use linear response theory [31]. and write

$$H'(t') = -\eta \Omega(t') \Psi^\dagger(t') + h.c$$

Here we presume that world is turned on at time t' very slowly, coupled to the self creation operator $\Psi^\dagger(t')$ with a coupling constant η . For the time being we omit the spatial index, to keep it simple. This perturbation will give the retarded response

$$\delta \langle \Psi(t) \rangle = -\frac{i}{\hbar} \int_{-\infty}^t dt' \langle [\Psi(t), H'(t')] \rangle \quad (45)$$

\mathcal{I} feels the change $\delta \langle \Psi(t) \rangle$ and is conscious of the change because the first order change $\delta \langle \Psi(t) \rangle$ brings about a second order change of the free energy of the ground state $\sim (\delta \langle \Psi(t) \rangle)^2$. *This response constitutes awareness of I to the world and we define it as cognitive perception*. Only a small part of this perception is a conscious perception and we call it our consciousness. *Precisely Consciousness results from that part of the response function which is dissipative or imaginary*. There is a whole part of the response function that we are not conscious of. Because cognitive response is considered to be ruled by causality, with response lagging behind the stimulation in time, we have retarded response function or susceptibility given by

$$\delta \langle \Psi(t) \rangle = \int_{-\infty}^t dt' \chi_R(t-t') \Omega(t') \quad (46)$$

Here the susceptibility is defined by the commutator

$$\chi_R(t-t') = -\frac{i}{\hbar}\theta(t-t')\langle[\Psi(t), \Psi^\dagger(t')]\rangle \quad (47)$$

The θ – *function* where $t \succ t'$ assures the causality, cause preceding effect.

We all know what it is to be unconscious. We also know what it is to be conscious or waking up to the hustle and bustle of the world. Unconscious state is a state of repose. Our brain is at its free energy minimum and world Ω is absent at this minimum. In deep sleep or general anesthesia, awareness of the world around us disappears. We take it for granted that it should be so. But there is a paradox in this. At this free energy minimum where \mathcal{I} is very much present, so is the cognitive response function, $\chi_R(\omega)$ which we just defined. Then why does the awareness go away? The precise answer lies in very nature of the cognitive response function which will also permit us to give an *operational definition of consciousness and unconsciousness*. Here the cognitive susceptibility is a retarded function (subscript R) given by the operator average

$$\chi_R(t-t') = \langle\Psi(t)\Psi^\dagger(t')\rangle, \quad t \geq t'$$

Defining cognitive susceptibility as a linear response function to the world, we have made the implicit assumption of causality. Its fourier transform is

$$\chi_R(\omega) = \int_0^\infty d(t-t') \langle\Psi(t)\Psi^\dagger(t')\rangle \exp[i\omega(t-t')]$$

The causality imposes on the $\chi_R(\omega)$ the Krammer's-Kronig relationship, *so that the response is a complex quantity*, having a real and an imaginary part (the two parts are related through Hilbert transform).

$$\chi_R(\omega) = \chi'(\omega) + i\chi''(\omega) \quad (48)$$

The imaginary part of the response function $\chi''(\omega)$ monitors *real neuronal excitation* from the ground state. This is the part that would give rise to real sensations, emotion and eventual dissipation of the excitation back into the outside world as heat and sensed by the organism as fatigue. *We define the imaginary part as Consciousness*. Since $\chi''(\omega)$ is odd in ω , $\chi''(\omega) = 0$, at $\omega = 0$. This explains why there is no conscious response when brain is at the free energy minimum. This minimum is situated at $\langle\Psi\rangle = 0$, for a baby ≤ 2 yrs old and at $\langle\Psi\rangle = \mathcal{I}$, for all other cases where selfhood has been achieved. We are unconscious at this precise point. Real part of cognitive response $\chi'(\omega)$ is finite of course due to virtual infon excitations. Conscious perception results only with the real excitations. *Subsequent decay of real excitations confer on them a life time or the time needed for us to be conscious of an event; the imaginary part consequently has a spectral weight over which the excitation energies are spread out, which we perceive as a conscious experience*. This rainbow hue of spectral spread is sensed by self (even when \mathcal{I} is not yet formed) as a direct perception of the world in all its splendour, called "qualia" of conscious experience [30]

The full $\chi_R(\omega)$ has poles in the lower energy ($\epsilon = \hbar\omega - i\delta$) plane that define the exact excitation energies with a small imaginary part δ .

We will address this issue in both cases: for babies less than 2-yrs old when one is at the free energy minimum of $\langle\Psi\rangle = \Phi = \mathcal{I} = 0$ and for children above that age when $\langle\Psi\rangle = \Phi = \mathcal{I} \neq 0$ when one is in the symmetry broken phase.

The approach to the coherent state free energy minimum is heralded by the static real part of $\chi_R(\omega = 0)$ which one does identify as *inverse* of \mathbf{A}

$$\frac{1}{\chi_R(\omega = 0)} = (\mathbf{A}) = \left(\frac{\partial^2 G(|\langle\Psi\rangle|^2)}{\partial^2 |\langle\Psi\rangle|} \right)$$

which goes to zero (susceptibility diverges, see appendix) as the cognitive order begins to develop. The imaginary part related to dissipation during cognitive perception *is what we assert to be conscious*. It includes the emotive part of the response, as the perception manifests itself, through visible emotion, palpable sensation, rapid eye motion or increased heart beat, skin temperature rise or sudden blips in the E.E.G signal in the γ -frequency region often characteristic of the awake conscious state. The real part $\chi'(\omega)$ is related to the lossy part $\chi''(\omega')$ through

$$\chi'(\omega) = \frac{1}{\pi} \int_{-\infty}^{\infty} d\omega' \chi''(\omega') P \frac{1}{\omega' - \omega} \quad (49)$$

Here P is the principal value integral over the lossy part of susceptibility. The integral says that if the real part of cognitive susceptibility on the left is to become large at $\omega = 0$, it can be so if the integral on the right with the imaginary part becomes more and more intense around the low energy response. This is clearly seen if we come down from the normal phase where there is as yet no cognitive order \mathcal{I} is still=0 (for a baby < 2 yrs) and approach the point when the real part of the cognitive response starts diverging. The imaginary part (see Appendix) of the susceptibility of any one given neuron i can be written

$$\text{Im } \chi_i^l = \frac{\rho_o \omega \tau}{(1 - \lambda \rho_o)^2 + \lambda^2 \rho_o^2 \omega^2 \tau^2}$$

Here ω is excitation energy measured from the equilibrium energy state and τ a characteristic relaxation time for relaxation of the excitation, ρ_o is a density of states of these info particles and λ a characteristic energy scale of synaptic connectivity. As the system starts going critical at $\lambda \rho_o \rightarrow 1$, when the real part starts to diverge, the imaginary part becomes more and more peaked at low energy. In the attached Figure 3.1 we plot, $\text{Im } \chi_i^l$ showing the series of curves reflecting the intensity of conscious experience as $\lambda \rho_o \rightarrow 1$ and the child (> 2 yrs old) acquires non-zero cognitive order ($\mathcal{I} \neq 0$).

This may explain why early childhood experiences are so intense. This abundance of low energy excitations is probably at the root of intensity of some conscious experience, and its 'qualia'.

There are several key remarks that should be made to make clear the ground on which we stand.

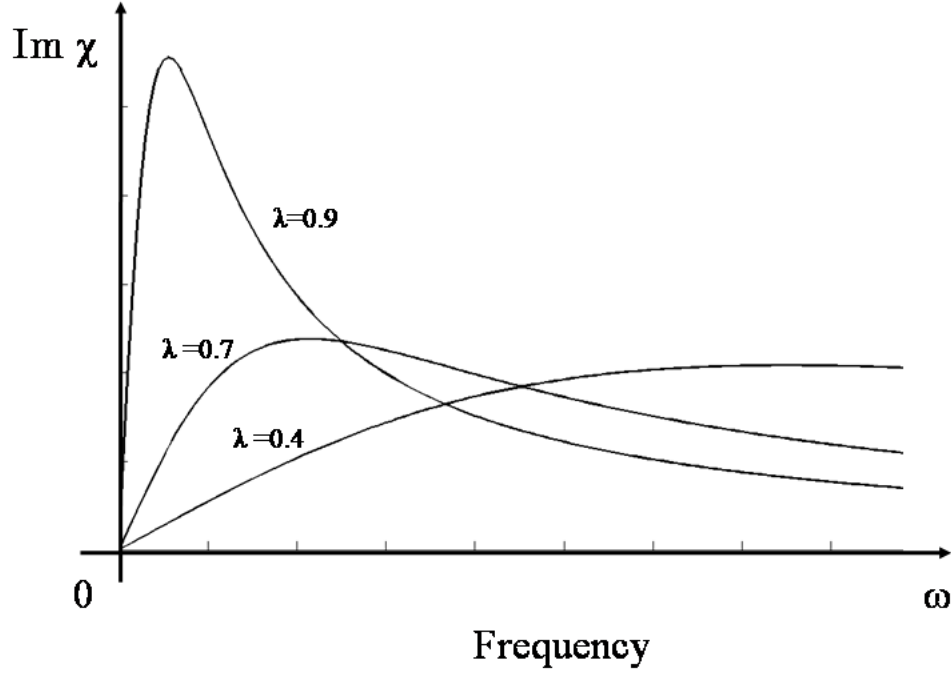


Figure 3: Approach to self as synaptic connectivity increases to threshold of consciousness.

(a) Although at $\langle \Psi \rangle$ at $\langle \Psi \rangle_{eq} = \mathcal{I}$, external world has vanished, one can be marginally conscious of dream like phenomenon. However, if one can avoid falling asleep and achieve this ground state through some techniques of profound meditation, the cognitive susceptibility will consist in consciousness of self without any awareness of the world. The perceiving self \mathcal{I} is very much present.

(b) The world springs into being as soon as $\langle \Psi \rangle$ moves out of the free energy minimum at \mathcal{I} and positions itself at any other point on the curve where the slope is given by

$$\left(\frac{\partial G(|\langle \Psi \rangle|^2)}{\partial \langle \Psi \rangle} \right)_{\langle \psi \rangle = \langle \psi' \rangle \neq \langle \psi \rangle_{eq}} = \Omega$$

The cognitive response will consist now of a significant part which is conscious response that we will call consciousness defined below. This consists in awareness of the world and of self.

(c) Two space-time events $\Omega(i, t)$ and $\Omega(j, t')$ will have relationship with each other when and only when, the events are negotiated through the cognitive

susceptibility. This is given by the free energy piece

$$\Delta F = \Omega(i, t) \chi_R(i - j, t - t') \Omega(j, t') \quad (50)$$

This has the immediate consequence that relationship discovered between phenomenon is mediated by our sensorial perception and is not independent of the cognitive mechanism that observes it. There is one little comment about the nature of physics that this last relationship underlines. In classical physics, observations between facts and relationships between them are out there to be discovered. In quantum physics, observables are only those that are not disturbed by the observation process itself; not all relationships between observables are possible. In the physics of consciousness, observation depends on the observer and relationships between objects are dependent on the perception χ_R of the observer. An absolute relationship between observables does not exist, as best is an illusion. But since the operator of self S is non-hermitian, its average, called \mathcal{I} the observer, is not Hermitian either. As a result, it is not a measurable or can be object of observation.

3.2 Memory and dynamics of Perception

We have seen that a symmetry broken ground state emerges which is immutable in space and time, characterised by the quantity \mathcal{I} , the cognitive order parameter which is a macroscopic manifestation of our penultimate *self*. We are permitted to replace the original vacuum state $|0\rangle$ that we started with by the new ground state which we call $|\mathcal{I}\rangle$. While $|0\rangle$ represented the nothingness of no information state of the original pristine mind, $|\mathcal{I}\rangle$ is the *full coherent state* that the self operator S or its synaptic counterpart Ψ has sculpted out of this primordial nothingness.

The basic infon propagator from one neuron i to another j is written as the Green's function

$$g(i - j, t - t') = \langle \mathcal{I} | \psi(i, t) \psi^\dagger(j, t') | \mathcal{I} \rangle \quad (51)$$

This is formally obtained from the Free energy expression F of the preceding section by differentiating it two times (here the average is over $|\mathcal{I}\rangle$)

$$\frac{\partial^2 F}{\partial \Omega(j, t') \partial \Omega^*(i, t)} = \langle \psi(i, t) \psi^\dagger(j, t') \rangle$$

This one particle Green's function constitutes the building block of our dynamic day to day or episodic memory in contrast to the ground state memory of the reservoir of infon particles N_o built out of genetic material that gave rise to \mathcal{I} . If we differentiate the free energy $2M$ times we get the M -point correlation function ,

$$\frac{\partial^{2M} F}{\partial \Omega(j, t') \dots \partial \Omega(M, t') \partial \Omega^*(i, t) \dots \partial \Omega^*(M, t)} = \langle \psi(i, t) \dots \psi(M, t) \psi^\dagger(j, t') \dots \psi^\dagger(M, t') \rangle$$

We make use of Bloch-deDominicis decomposition [34] to get all combinations of two by two factors to get the average of a product of creation and annihilation operators that gives us

$$\langle \dots \rangle = \sum_{all\ i,j} \langle \psi(i,t) \psi^\dagger(j,t') \rangle$$

This is our dynamic memory matrix, M_R a $M \times M$ matrix, given by

$$\langle \dots \rangle = \begin{bmatrix} \psi_i(t) \\ \psi_j(t) \\ \dots \\ \psi_M(t) \end{bmatrix} \left[\psi_i^\dagger(t') \dots \psi_M^\dagger(t') \right] = \mathcal{M}_R$$

The expression $\left[\psi_i^\dagger(t') \dots \psi_M^\dagger(t') \right]$ is a short hand for expressing that at some past time t' a page of a book was written with infons on different synaptic sites $i, j, \dots M$ etc. It is like an instantaneous photograph at the instant t' of the states of occupation of the synapses. The ket associated just on its left the long

column $\begin{bmatrix} \psi_i(t) \\ \psi_j(t) \\ \dots \\ \psi_M(t) \end{bmatrix}$ is telling us that the same page is being read at the very

present moment t , or another photograph of the same set of sites is being taken at the instant, t . If the tensor product has a non-zero joint amplitude i.e if the two sets of photographs match, then one has memory of what happened at the instant t' . If there is decoherence in propagation of infons between these two times, then memory will be impaired. This can be written more succinctly as retarded susceptibility function $t \geq t'$, with a subscript R

$$\chi_R(t - t') = -\frac{i}{\hbar} \theta(t - t') \langle [\Psi(t), \Psi^\dagger(t')] \rangle = matrix\ \mathcal{M}_R \quad (52)$$

Here $\Psi(t)$ is the synaptic site destruction operator matrix

$$\Psi(t) = \begin{bmatrix} \psi_i(t) \\ \psi_j(t) \\ \dots \\ \psi_M(t) \end{bmatrix}$$

and $\Psi^\dagger(t')$ is the creation operator matrix given by $\left[\psi_i^\dagger(t') \dots \psi_M^\dagger(t') \right] \cdot \left[\psi_i^\dagger(t') \dots \psi_M^\dagger(t') \right]$.

It is instructive to look at the Fourier transform $\chi_R(\omega)$ of $\chi_R(t - t')$ as $t - t' \rightarrow \infty$

We write

$$\chi_R(\omega) = \int_{-\infty}^0 dt \exp i\omega(t - t') \chi_R(t - t')$$

There is no guarantee that such a Fourier transform exists, particularly if it exists in the limit of $\chi_R(\infty)$. That would imply permanent memory. But if it does,

we can write is as

$$\chi_R(\omega) = \chi_R(\infty) \delta(\omega) + \chi_R(\omega \neq 0)$$

The second term of this expression contains contribution of all the short term memories, while the first term tries to catch all episodic memories which we call our autobiography. It is static and time does not efface it and retrievable at any instant t , if we had the means to do so. They seem to be gone most of the time but they are not. Under external stimulation sometimes they surface bursting into our consciousness as fishes out of the deep sea, surprising us.

Finally, there is the instantaneous memory given by

$$\chi_R(t = t') = \int_{\omega} \chi_R(\omega) d\omega \quad (53)$$

Instantaneous memory is the integrated energy response of the neural system. These three regimes are shown in Figure 3.2.

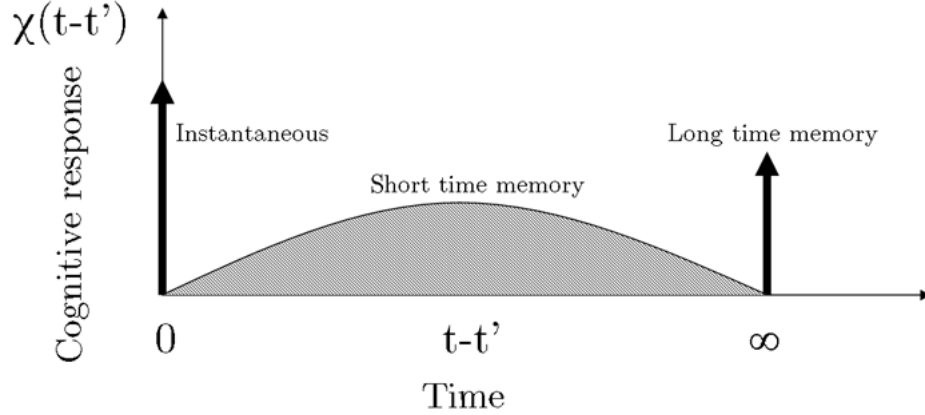


Figure 4: Dynamic memory. Time correlation of cognitive response : instantaneous, long time and short time memory.

The infinite temporal correlation between infon particles when it exists becomes the fabric of our dynamic memory matrix. *This memory tape is eternally preserved except in pathological situations.* The whole aspect related to decoherence and memory loss is intended in a future publication.

The cognitive susceptibility, is given by single particle Green's function or propagator because it describes propagation of information from one space-time point to another. Trasformed in the Fourier space, it describes the same information carrying a momentum q (although momentum is not a good quantum number in a non-homogeneous system) and excitation energy ω . Perturbation due to external world causes an excitation from the ground state $|I\rangle$. we will

designate this excitation by the global consciousness operator φ_c

$$\varphi_c = \Psi - \langle \Psi_C \rangle \quad (54)$$

The consciousness annihilation operator has the operational definition

$$\varphi_c |\mathcal{I}\rangle = 0 \quad (55)$$

φ_c^\dagger creates quasiparticles. *The state $|\mathcal{I}\rangle$ is the vacuum of consciousness carrying quasiparticles. When one is at the ground state $|\mathcal{I}\rangle$ one has no consciousness. We will be in the Heisenberg representation where this symmetry broken ground state $|\mathcal{I}\rangle$ is immobile in time while the consciousness operators are time dependent. Hermitian conjugate of the annihilation operator φ_c is the creation operator φ_c^\dagger of a consciousness quasiparticle given by*

$$\varphi_c^\dagger |\mathcal{I}\rangle = 1 |c\rangle$$

Here $|c\rangle$ is an excited state describing consciousness.

Quasiparticle excitation is a single particle response. We shall now outline a microscopic sketch of what is involved in single particle excitation that causes consciousness. We express it in terms of local consciousness operator, $\varphi_c(i, t)$ as

$$\varphi_c(i, t) = \psi(i, t) - \langle \psi(i) \rangle \quad (56)$$

Write for single particle Green's function or the excited state information propagator

$$g(i - j, t - t') = \langle \varphi_c(i, t) \varphi_c^\dagger(j, t') \rangle \quad (57)$$

We can expand just one single particle propagator, of a piece of information going from neuron j to i

$$\begin{aligned} \langle \varphi_c(i, t) \varphi_c^\dagger(j, t') \rangle &= g(i - j, t - t') = g_o(i - j, t - t') \\ &+ g_o(j - k, t' - t'') \Sigma(k - i, t'' - t) g(i - k, t - t'') \end{aligned} \quad (58)$$

The first term on the right hand side is the amplitude of direct propagation of information from $j \rightarrow i$ and from $t' \rightarrow t$. The second term describes the same process but takes into fact that propagation may not be direct and can go through many an indirect channels (like an intermediate neuron k) before reaching the destination neuron i . We can go to the Fourier space (since neurons are distinguishable, q is a poor quantum number),

$$\varphi_c(q, \omega) = \int_t \int_r d(i - j) d(t - t') \varphi_c(i - j, t - t') \exp i q(r_i - r_j) \exp i \omega(t - t')$$

we define

$$g(q, \omega) = \langle \varphi(q, \omega) \varphi^\dagger(q, \omega) \rangle \quad (59)$$

This propagator has poles where the amplitude becomes very large and occurs at specific values of ω . The corresponding excitation carries a q and ω label as it travels. Thus every thought and emotion which correspond to these excitations carry real momentum and real energy.

$$g(q, \omega) = g_o(q, \omega) + g_o(q, \omega) \Sigma(q, \omega) \} (q, \omega) \quad (60)$$

$$g(q, \omega) = \frac{g_o(q, \omega)}{1 - g_o(q, \omega) \Sigma(q, \omega)} \quad (61)$$

The function $\Sigma(q, \omega)$ is the fourier transform of the self energy of the fluctuation green's function written earlier in real space-time as $\Sigma(r'' - r, t'' - t)$. The non-interacting green's function is $g_o(q, \omega)$ is a high energy process, has a pole at $\omega = \epsilon_q$, which is the energy needed to excite a particle out of the condensate or ground state. It automatically confers the same pole to $g(q, \omega)$.

$$g_o(q, \omega) \approx \frac{1}{\omega - \epsilon_q}$$

This high energy excitation is subconscious perception process because the information is carried swiftly from one spot to another. This is the amplitude mode that is expected to have an energy gap $\epsilon_q \approx \Delta$ for excitation.

The lower energy excitation comes from the indirect path and is given by the second pole $g(q, \omega)$ and occurs where the denominator of the expression 61 goes to zero. This will happen whenever

$$g_o(q, \omega) = \frac{1}{\Sigma(q, \omega)} \quad (62)$$

If this occurs at $\omega = o$, then the real part of $g(q, \omega)$ has diverged leading to phase transition while the imaginary part is related to the real part through expression of 49. The spectral weight of these low energy long lasting or slow response excitations is to be identified as the bulk of our conscious experience. *The Spectral weight $\mathcal{A}(q, \omega)$ of these excitations have a life time and come essentially from the self energy part of the propagator and is given by [35]*

$$\mathcal{A}(q, \omega) \approx \text{Im } \Sigma(q, \omega)$$

The spectral weight has the simple expression

$$\mathcal{A}(\omega) = \sum_{\omega_n} [\langle n | \Psi^\dagger | 0 \rangle]^2 \delta(\omega - \omega_n)$$

This shows that external world causes real neural excitations, the delta function in the energy summation assures energy conservation, while the square of the matrix element gives us the intensity of the excitation spectrum. These single excited particle states constitute bulk of the amplitude mode. These are dissipative modes and hence lead to genuine conscious perception process.

Our ground state defined by the minimum of Gibb's free energy at $T = T_R$, is where world Ω is absent (at this minimum). This is analogous to screening out of magnetic field by a superconductor. Our \mathcal{I} sits in this energy minimum and fluctuates out of this minimum when interacted on by the world. This \mathcal{I} has an amplitude and a phase, the unique phase of the broken symmetry. The single particle propagation operator $\varphi_c(i, t)$ that we described describes the amplitude oscillation and is an amplitude mode. It exists even if \mathcal{I} is zero as long as $|\mathcal{I}|$ is non-zero. It is a high energy mode, is an amplitude fluctuation, where creation of quasi-particle like excitation i.e: infon particles require finite energy. These have a gap Δ or 'mass'. We can give a number to the gap if we recall that the critical voltage necessary to initiate action potential along an axon is typically ~ 100 mv. This can be taken as the value of Δ . Because of θ -symmetry breaking, there is a second fluctuation mode in the potential well of the Mexican hat[33]. This one (present only when $\mathcal{I} \neq 0$) is the low energy mode, due to phase θ -fluctuation, where the order parameter fluctuates locally along the "ring of the mexican hat along the minimum energy". This phase fluctuation mode is also known as Goldstone mode and is a phonon, whose energy is given by (if the infons are charge neutral)

$$\hbar\omega_q = vq \quad (63)$$

It is a gapless collective mode where v is the velocity of mode propagation. This really just a density fluctuation and is sound wave like. Because of the gap in the single particle excitation spectrum, the sound wave like mode has virtually no dissipation or damping in the low energy sector. We like to associate this mode with consciousness of thought like processes. Here the excitation may be carried as a soliton or a sound packet, going over a large distance adiabatically, losing no energy in the transport. Because it is a very stable mode, it has virtually no decay channel or imaginary part except at higher q - *vectors* where it will merge into the continuum of the amplitude mode and will dampen and become part of emotional perception. We cannot be too conscious of short q (long wave length), low ω (very low energy) thought waves; they will remain subliminal. On the other hand, the quasiparticle like amplitude oscillation can have a fairly large imaginary part corresponding to real excitation but with a life time. This we believe is responsible for consciousness of emotional processes.

Phase and amplitude mode will couple if phase fluctuation, which is density fluctuation couples with amplitude fluctuation, which is a single particle excitation. There is a neural cut off at low and high energy. A violent shock that makes \mathcal{I} go over the high energy threshold is not perceived by the mind, because precisely those regions have no spectral weight. As a result of the shock, we may become unconscious *catapulting I to a metastable equilibrium a different extremum of free energy. All conscious perception of the incident including pain, that accompanied the intense shock, vanishes.*

In this section we have seen that cognitive response due to particle excitation has two essential channels. One is the swift response, often needed for biological survival, which is a high energy virtual excitation process and is

largely subconscious. It is instantaneous reaction and we are barely aware of what is going on. The second channel is the slow response, the propagator takes routes and detours, uses low energy circuits and loops, is mainly dissipative because it is the imaginary part of overall cognitive susceptibility. This is at the root of conscious perception.

4 Discussion

The all - important self operator, has carved out of mind-space, cognitive order or the \mathcal{I} -field. It pervades uniformly whole space. It has given rise to a spatio-temporally homogeneous order parameter \mathcal{I} that constitutes our mental base. This \mathcal{I} is the executor of what we call, **our mind**. One cannot give a specific neuron label to it; in order to get it, we have integrated over all the neuron coordinates. We have asserted that This \mathcal{I} and synaptic self are identical. This is a highly questionable assertion. So far there seems to be no concrete evidence of \mathcal{I} surviving loss of personal memory or other pathological neural disorder which seems to justify it. Penfield seems to think the contrary. It is of interest to quote from Penfield:[36] *"It is what we have learnt to call the mind that seems to focus attention. The mind is aware of what is going on. The mind reasons and makes new decisions. It understands. It acts as though endowed with an energy of its own. It can make decisions and put them into effect by calling upon various brain mechanisms. It does this by activating neuron-mechanisms."* And he says a little further that *"there is no place in the cerebral cortex where electrical stimulation will cause a patient to believe or to decide."* Hence one should be very cautious about our assertion.

As we have seen \mathcal{I} is also synchronous with our memory, which in reality is a huge ($10^{11} \times 10^{11}$) matrix constituted with local cognitive order on each and every neuron and space-time correlation between them. When parts or whole of memory is gone, we lose our sense of the precious \mathcal{I} . The global cognitive order has phase coherence because it has got a fixed phase θ , a different one for every brain and which confers on each one of us, the unique personality that we have. When we are in our ground state, at the minimum of the free energy parabola, there is neither world or world awareness. Any fluctuation of \mathcal{I} can only be local in space and time and gives rise to vastly different excited states $\{m\}$ of the mental space.

Operators s_m are non-hermitian and the world they create are real but not measurable in the physical sense. The essence of sensory experience, named 'qualia' by philosophers, that includes colour, harmony, odor and alas pain are only too real, none measurable (not Hermitian), nor *explainable* by the physical nature of the stimuli. When one comes to think of it, physical properties that we attribute to things is not an intrinsic characteristic of the outside world. These are created by s_m operators in the mental space.

The vacuum state $|0\rangle$ on which the exponentiated creation self operator ψ^\dagger acts *is the pure genetic material in the chromosomic soma of every neuron*. The operation is the attempt by self to express and make explicit the unique

physical identity of each individual \mathcal{I} . This is the unconscious cognitive state *affirming pure bodily self*, a process that must start in the womb in the very first weeks after conception. The operator operates in anticipation of future, prepares the representation of the body and bodily related cognitive function in the brain. The motor area will be active to help in this representation; the Penfield Homunculus[13] map would begin to be etched out. Sensations will follow upon birth and find templates ready, unto which thoughts can latch into. All this is still in the future, all this is a premonition of that future. One can almost say that cause of all this activity is in the future, that \mathcal{I} causes itself ! It would continue long into the second year of the baby after birth, to incorporate the varied input from the outside sensory world so as to add the conscious *narrative self* to the zeroth order bodily self and thus complete the individuation process.

Organisms have to be understood as a mesh of virtual selves. As Varela put it " *I don't have one identity, I have a bricolage of identities. I have a cellular identity, I have an immune identity, I have a cognitive identity.* " [37] The s_m and its Hermitian conjugate s_m^\dagger operators are operators of self and as such they are embedded into our genetic identity. They are simply there and go on creating a variety of instruction protocols that are needed for the brain to be the wonderful smooth machine it is. They start acting as soon as the first group of neurons are functional in the womb and create out of the genetic endowment of each individual a world of representations that are previsual, prelexique, a primordial world of ideas and sensations and categories only, before being named or verbalised. The cognitive ground state of the baby brain, as soon as the cognitive order parameter $\langle\psi\rangle$ or \mathcal{I} is non-zero (when it is about 2 yrs old) is ready to interpret the outside world and to extract a coherent meaning out of the divers exterior stimuli. From the outside world, both consciousness and memory will form. But in the construction of \mathcal{I} , *only* the genetic material is transcribed and that will serve as a template for the world outside. Through this \mathcal{I} , the world within will meet the world without.

Blocking of θ at an arbitrary value is called symmetry breaking. This often occurs in certain class of phase transitions , where a lower symmetry ordered phase emerges from a higher symmetry chaotic phase. In our case emergence of \mathcal{I} signifies a rupture of the multidimensional $U(N)$ symmetry, from objectivity to subjectivity establishing a genetic affirmation of personality. Each θ is a different individual, a completely different view of space-time. Blocking of global θ at some value and that remains blocked signifies an extraordinary phase stiffness. In order for this to happen, the infon population N_o must be large and vary a great deal. This number varies because brain is plastic and the fluidity of the information flow is matched by continuous birth and death of synaptic connections. Because the brain is an open system, open to the world, the information content as well as their number is a continually fluctuating quantity. This flux and influx of information is precisely the condition necessary to achieve a phase coherent state. The information must fluctuate a great deal around some average value which permits brain to achieve phase coherence between different parts and we can extract a coherent meaning from our sen-

sory input. Nothing prevents θ to fluctuate locally and give rise to excitations in the mind which are mind waves. These excitations could be collective and massive extended through the whole system as in an epileptic seizure or could be single particle like, intense and localised, like spikes of pain. Importance is maintaining the phase coherence, no matter what and in this \mathcal{I} is both witness and regulator of coherence and assures a maximum of information flow, including contradictory information so as to create the overall meaning. The traffic exchange between different neurons through the synaptic clefts is a key player in this game. Nothing is more eloquent in this respect than the behaviour of the two hemispheres of the brain, left and right. The left brain is analytical, logical, time sensitive, while the right processes information in a holistic way rather than breaking them down and more involved with sensory perception rather than abstract cognition. Between the two hemispheres is a thick bundle of axons or nerve fibers, about 80 million called *corpus callosum* that handles the heavy traffic of information without which we shall not get a global conscious coherent state. If this traffic is interrupted, personality disorder will arise, and most likely two different coherent states, one on the left and another one on the right will rise and exist side by side. Symmetry breaking into more than one Θ is conceivable in certain cases of brain disorder where the free energy of the two Θ -states being the same, the ψ -operator will flip-flop between two equivalent metastable equilibrium and the resultant personality will effortlessly slip from one into other *but with the same sense of “ \mathcal{I} ”*. Here we may quote the noted neurologist Ramachandran [38] who writes ” The sense of ‘unity’ of self also deserves comment. Why do you feel like ‘one’ despite being immersed in a constant flux of sensory impressions, thoughts and emotions?Perhaps the self by its very nature can be experienced only as a unity.” And a little further ” Even people with so-called multiple personality disorder don’t experience two personalities simultaneously— the personalities tend to rotate and are mutually amnesic”.

The brain order parameter Φ_{eq} , at the free energy minimum represents the lowest energy state of the cognitive system. The order parameter Φ represents a whole landscape of free energy valleys and hills (different states of awareness) rather than one absolute minimum. *The \mathcal{I} that emerges is a tremendous transition from the Self that is simply an operator ψ to what becomes \mathcal{I} am.* This \mathcal{I} can be thought as a self appointed instructor of the cognitive machine: the \mathcal{I} that lives, governs and presides over our thought, action, emotions and our dreams.

We want to make a comment here about Dream state. If from a state of consciousness, the organism enters rapidly into sleep, world would not have had time to be totally expelled or annealed out, before falling asleep. This remanence of the world, these trapped flux of world-lines, resemble trapped magnetic flux in a superconductor as it is cooled in a magnetic field, and may be the cause of vivid dreams. These dream states cannot be eliminated and the system will oscillate between deep dreamless ground state of sleep and patches of dream where local neuronal excitations continue to persist.

Before ending this discussion, a word may be appropriate about these self

operators we have employed. Sakurai [41] had written à propos the creation, destruction and preservation operators used in quantum mechanics that these *"three operators correspond respectively to the Creator (Brahma), the Destroyer (Siva), and the Preserver (Vishnu) in Hindu mythology."* If anything the operator of cognitive Self s_m fits perfectly this description. Self creates, self destroys, self also preserves. Between this triad of operators, $S = \{s_m^\dagger, s_m, n\}$ that we may designate by the symbol S , the whole human drama is enacted.

5 Appendix

We shall give here a simple model hamiltonian that captures the role of synaptic connectivity to bring about global consciousness response when a single neuron gets connected to other neurons. We borrow for the purpose the simple tight binding hamiltonian of electrons from solid state physics?? .

The response of a single neuron i , called χ_i^o is defined as (superscript zero, signifying zeroth order)response function in the absence of external perturbation

$$\chi_i^o(t) = \langle \psi_i(t) \psi_i^\dagger(o) \rangle ; \chi_i^o(\omega) = \int_{-\infty}^{\infty} dt \chi_i^o(t) \exp i\omega t \quad (64)$$

As we have already expressed, in the presence of *external force* F_i , acting on the neuron i we can write

$$\langle \psi_i(\omega = 0) \rangle = \chi_i^l(\omega = 0) F_i$$

Here $\chi_i^l(\omega = 0)$ is the full interacting local susceptibility of the single neuron, when it is giving and receiving signals to and from all other neurons. First we write down the simplest hamiltonian we can that catches the essential dynamics of information transfer between neurons and also between neurons and the world.

This is written as sum of three essential parts

$$H_n = \sum_i \epsilon_i n_i - \mu \sum_i n_i + \sum_{i,j} V_{ij} n_i n_j \quad (65)$$

$$H_t = - \sum_{i,j} \left(T_{ij} \psi_i^\dagger \psi_j + h.c \right) \quad (66)$$

$$H_{ext} = \sum_i g_i \left(\Omega_i \psi_i^\dagger + \Omega_i^* \psi_i \right) \quad (67)$$

Here H_n is the hamiltonian that has onsite site energy ϵ_i , chemical potential μ of infon on each site i as well as some assumed repulsive energy between neuron population at sites i and j The part of the hamiltonoian $H_0 + H_t$, when written for bosons is well-known. In the special case, when V_{ij} is repulsive and if $V_{ii} = \infty$, no two bosons can occupy the same site (hard core limit). The lattice

hamiltonian we used, in the hard core boson limit in translationally invariant lattice is well -known to possess a superfluid ground state. [43] Neuron network in human brain is highly irregular, is plastic, the synaptic interconnections are far from being identical and continually evolving. Any conclusion about its superfluidity should await a long time until we can have clean non-invasive experimental data.

The all important tunneling of information from neuron i to neuron j is given by the tunneling (also called hopping) matrix element T_{ij} through the synapses in between. The expression $h.c$ within the bracket signifies the reverse or hermitian conjugate process of info-transfer from j to i . The term H_{ext} of the hamiltonian expresses interaction of the neuron with the external world. This includes one's own body exterior to the cognitive system as well as the world around. The first three terms can be written in the Hartree form as pure onsite part. We thus divide the Hamiltonian in two parts,

$$H_n = \sum_i H_i + H_{int} \quad (68a)$$

$$H_i = \epsilon_i n_i - \mu n_i + V_H n_i \quad (68b)$$

$$where \quad V_H = \sum_j V_{ij} \langle n_j \rangle \quad (68c)$$

$$H_{int} = - \sum_{i,j} (T_{ij} \psi_i^\dagger \psi_j + h.c) + \sum_i g_i (\Omega_i \psi_i^\dagger + \Omega_i^* \psi_i)$$

The term V_H is the Hartree term and has been absorbed into the site energy ϵ_i . The term H_{int} contains interaction with other neurons and with the world. The all-important tunneling Hamiltonian will be simplified as

$$H_t = - \left[\sum_{i,j} T_{ij} \langle \psi_j \rangle \psi_i^\dagger + \sum_{i,j} T_{ij} \langle \psi_i^\dagger \rangle \psi_j \right] + \sum_{i,j} T_{ij} \langle \psi_i^\dagger \rangle \langle \psi_j \rangle + h.c \quad (69)$$

The first two terms of the equation 69 act like a molecular field on the information operators at i & j . The last term is just a c-number that we neglect since it does not have any operator character. We want to express the interaction hamiltonian into a molecular '*Weiss Field*' acting on the site i . We first consider just nearest neighbor tunneling to get an order of magnitude idea of the effect of the molecular field of nearest neighbors or short range tunneling on the static ($\omega = 0$) single neuron susceptibility. This is given by

$$H_t^o = -\nu T_{nn} \left[\langle \psi_j \rangle \sum_i \psi_i^\dagger + \langle \psi_j^\dagger \rangle \sum_i \psi_i \right] + h.c \quad (70)$$

Here ν is the number of first near-neighbor neurons ($\sim 10^4$) of a given neuron connected through synapses, with an average tunneling amplitude T_{nn} . T_{nn} has

the dimension of energy. Thus the tunneling term gives a Weiss molecular field contribution acting on the site i

$$F_t = -\nu T_{nn} \langle \psi_j \rangle$$

Similarly external world acts with a ‘force’

$$F_{ext} = -g\Omega_i$$

This permits us to write

$$\langle \psi_i \rangle = \chi_i^o [g\Omega_i + \nu T_{nn} \langle \psi_j \rangle]$$

We make now the homogeneity assumption $\langle \psi_j \rangle = \langle \psi_i \rangle$ and write a mean-field susceptibility

$$\langle \psi_i \rangle = \chi_i^l \Omega_i$$

The R.P.A or mean-field interacting susceptibility is now expressed in the compact form

$$\chi_i^l = \frac{\chi_i^o}{1 - \nu T_{nn} \chi_i^o} \quad (71)$$

For a ‘free’ particle like behaviour of infons in the symmetry unbroken phase, we may write the real and imaginary part (as a Hilbert transform of the real part) of the non-interacting susceptibility as

$$\begin{aligned} \text{Re } \chi_i^o &\approx \rho_o \\ \text{Im } \chi_i^o &\approx \rho_o \omega \tau \end{aligned}$$

Here ρ_o is density of states of the infons (number of infons per unit energy per unit volume) as $\omega \rightarrow 0$, and τ is a characteristic relaxation time of the excitations, assumed frequency independent. Now we can equate the real and imaginary part of the interacting susceptibility of expression 71 and obtain

$$\text{Re } \chi_i^l = \frac{\rho_o - \lambda \rho_o^2 (1 + \omega^2 \tau^2)}{(1 - \lambda \rho_o)^2 + \lambda^2 \rho_o^2 \omega^2 \tau^2} \quad (72)$$

The imaginary part is given by

$$\text{Im } \chi_i^l = \frac{\rho_o \omega \tau}{(1 - \lambda \rho_o)^2 + \lambda^2 \rho_o^2 \omega^2 \tau^2} \quad (73)$$

Here we have written the symbol λ for a characteristic energy parameter of synaptic connectivity,

$$\lambda = \nu T_{nn}$$

The real part of interacting susceptibility as $\omega \rightarrow 0$ blows up as $\lambda \rho_o \rightarrow 1$. This gives us the critical value of neuronal connectivity when $\rho_o = \frac{1}{\nu T_{nn}}$. *This infinity signifies an instability and a phase change indicating a new cognitive*

state for the child, that of self consciousness developing rapidly out of consciousness. The phenomenon has a great degree of similitude to superconductive instability[44]. This is precisely the point where A , the coefficient of the second order term in the Ginzburg- Landau expression of the preceding section, goes to zero $\left(2A = \frac{1}{\sum_i \chi_i^l(\omega=0)}\right)$. From this point onwards, A can be negative, free energy function races to a stable minimum at the non-zero value of Φ_{eq} . \mathcal{I} can emerge as a self conscious self.

6 Conclusion

In conclusion we can summarise our investigation of Consciousness as a three step approach :

First and foremost we have defined Mind as a quantum field whose excitations are called quanta of information .

Second, we have defined a quantum operator S representing self, whose action on the mind vacuum state called $|0\rangle$ generated a coherent macroscopic functional space of mind where a non-zero average of the self operator emerged as \mathcal{I} . This $|\mathcal{I}\rangle$ field replaces the original vacuum $|0\rangle$ state and is our personal ground state of the mind.

Finally, energy excitations out of this ground state, as a result of interaction with outside world, is perceived by \mathcal{I} as being conscious of the world. Consciousness is defined as a causal response function that vanishes when one is in the true ground state $|\mathcal{I}\rangle$.

Acknowledgement

I want to acknowledge my deep indebtedness to Philippe Nozières of College de France for teaching some of us over the years many aspects of quantum fluid including Bose-Einstein condensation and superfluidity. I am also grateful to professor Jean Perret, former head of the department of Neurology at University Joseph Fourier, Grenoble for his series of lectures on human brain.

Many persons contributed through their discussions with me. I want to thank particularly Prof Ferdinando de Pasquale of University of Rome, La Sapienza, dept of Physics, for bringing to my attention analogies with Quantum decision theory, to Dr Amitabha Chakrabarti of Ecole Polytechnique, Paris for very perceptive comments about emergence of 'I', to Dr Mario Cuoco of Physics Dept, University of Salerno, to Prof T.V. Ramakrishnan of The Physics Dept, University of Benaras, India for pointing out importance of Self in Indian Philosophy. Thanks are also due to Prof Philippe Nozieres for questioning quantum nature of brain processes and to Dr Timothy Ziman of Theoretical Physics, Institut Laue-Langevin, Grenoble for suggesting that emergence of consciousness may have to do with time scales. Finally Jeanine and Kolyan Chakraverty bore the brunt of many interrogations on the subject with me these past years, shared some of their insights and I am grateful for that.

References

- [1] J.J.Hopfield , Rev Mod Phys, 71,431-437 (1999)
- [2] D.Amit ” Modeling Brain Functions ” (Cambridge University Press, Cambridge, 1989).
- [3] H.Haken ” Brain Dynamics ” (Springer, Berlin 2008)
- [4] N.Bohr, Naturwissenschaft, 17, 483-4486; also ” Light and Life”, Nature 131,421-423 (1933).
- [5] R.Penrose, ” The Emperor’s New Mind ” (Oxford University Press, Oxford 1989).
- [6] J.Satinover ” The Quantum Brain ” (Wiley, New York, 2001).
- [7] H.Frohlich Phys Lettr, A, 402 , 26, (1968)
- [8] F.Beck & J.Eccles, Proc NAt. Acad. Sci, U.S.A , 89,11357 (1992).
- [9] Giuseppe Vitiello ” My Double Unveiled ” (John Benjamins Publ, Amsterdam, 2001), Chapter 5.
- [10] I.Yukalov and Didier Sornette, ar Xiv /0802.3597v3 [physics.soc-ph] 17 march, 2010 and references therein.
- [11] W.Penfield & P.Perot, Brain 86 (1963) 595-696
- [12] T.Green, Stephen Heinemann & Jim Gusella, Neuron, (1998) , 420
- [13] M.F.Bear, B.W.Connors & M.A.Paradiso, ”NEUROSCIENCES” (Lippincourt Williams & Williams),23
- [14] A. R. Damasio ”Descartes’ Error” (Quill, Harper Collins Publishers, New York,2000) p123.
- [15] C.Sherrington ”Man On His Nature ” (Cambridge University Press 1963)
- [16] Von J. Neumann, ” Mathematical Foundations of Quantum Mechanics” (Princeton University Press, Princeton, 1955).
- [17] M.A.L. Nicolelis et al, JI of Neuroscience, 25 (2005),4681; The New York Times, page 6, section ” Science & Technology ”, 26th january, 2008
- [18] R.J.Glauber, Phys Rev 130 (1963),25296 (2005)
- [19] P.Cabannis, ” Trinité de Physique et Moral de L’Homme “ Second Memoir ” (1802)
- [20] T.D.Newton and E.P.Wigner, Rev Mod Phys, 21 (1949) 400

- [21] R.P.Feynman and A.R.Hibbs, " Path Integrals and Quantum Mechanics " McGraw Hill, New York, 1968.
- [22] P.A.M Dirac, The Principles of Quantum Mechanics (Clarendon Press, Oxford, 1958).
- [23] S.N.Bose, Z.Phys,26,(1924) 178
- [24] Thomas Nagel , " The View from Nowhere" (Oxford University Press, 1986).
- [25] Alexander Fetter & John Walecka, " Quantum Theory of Many Particle Physics " (Mcgraw -Hill Book Company ,Newyork,1971) 12.
- [26] Leonard Mandel & Emil Wolf " (Optical Coherence & Quantum Optics " , (Cambridge University Press, 2008),522
- [27] Joseph Ledoux " Synaptic Self "(Penguin Books,2002),67.
- [28] S.Coleman " Aspects Of Symmetry " (Cambridge University Press, Cambridge, 1985), chapter 5.
- [29] Jonathan Shear (ed) " Explaining Consciousness —The 'Hard Problem' " (MIT Press,1997).
- [30] David J. Chalmers, " The Conscious Mind " (Oxford University Press,)1996.
- [31] David .Pines & Philippe Nozières, " Theory of Quantum liquids", Vol 1, (Addison-Wesley , Newyork, 1988), 95.
- [32] P.G.de Gennes " Superconductivity of Metals and Alloys "(Addison-Wesley, Newyork 1989),171.
- [33] John Negele & Henri Orland " Quantum many Particle Systems " (Addison Wesley, Newyork 1988), 217.
- [34] C.Bloch & C.deDominicis - Nucl Physics 7 (1958) 459.
- [35] Gerald D. Mahan, " Many-Particle Physics " (Plenum Press, Newyork, 1990) 145.
- [36] Wilder Penfield, " Mystery Of The Mind " (Princeton paperbacks, Princeton University press,1978) 75.
- [37] Francisco Varela, " The Third Culture: Beyond the Scientific Revolution " by John Brockmann, chapter 12 (Simon & Scuster, 1995).
- [38] V.S.Ramachandran " The Emerging Mind " - The Reith Lectures, 2003 (Profile Books, London) 123.

- [39] Roger Penrose, " Shadows of The Mind " (Oxford University Press, 1994) 204
- [40] Philip Philipps & Denis Dalidovitch, SCIENCE vol 302, (2003),243.
- [41] J.J.Sakurai, " Advanced Quantum Mechanics" (Benjamin/ Cummings Publishing, California) 27.
- [42] Neil W. Ashcroft & N.David Mermin– " Solid State Physics "
- [43] T.Matsubara & H.Matsuda, Progr Theor Physics 16 (1956) 569.
- [44] B.K.Chakraverty, Phys Rev B, 48 (1993) 4047.